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ABSTRACT

The revised instructor's guide, which is part of the New York State Highway Technician's Program to provide needed technicians and engineers by upgrading people in the lower-level technician jobs, is geared toward the improvement of technical skills and knowledge in highway surveying. In view of the shortage of qualified technicians and engineers caused by the rapid expansion in the building of State and Federal highways, local school districts and other sponsors of adult education programs are being encouraged to offer the courses in this program as part of occupational education. Each of the fourteen lessons includes enough subject matter for about 2 1/2 hours of classroom instruction. All lessons are written with a content outline on the left half of the page and corresponding teaching points and techniques on the right half of the page. Lessons cover technical skills, such as: elements of surveying; measuring distances; leveling, measurement of angles and directions; the transit; traverse and stadia surveying; field astronomy; horizontal and vertical curvature; preliminary, construction, and final surveys. Also included is a final examination. (EA)

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program for
highway
technicians

teacher's guide

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Unit III
Highway Surveying

The University of the State of New York
THE STATE EDUCATION DEPARTMENT
Bureau of Continuing Education
Curriculum Development
Albany, New York 12224, 1971

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HIGHWAY SURVEYING

Instructor's Guide for an Adult Course

Highway Technicians Program
UNIT III

The University of the State of New York
THE STATE EDUCATION DEPARTMENT
Bureau of Continuing Education Curriculum Development
Albany, New York 12224
1971

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FOREWORD

This instructor's guide, *Highway Surveying*, is a revision of Unit III in the Highway Technicians Program. It was produced by the New York State Education Department with the help of the New York State Department of Transportation (formerly the Department of Public Works), which had requested the program originally.

John L. DeLee, now principal civil engineer in the Bureau of Highway Planning of the Department of Transportation, (with the help of other personnel from the district offices of the Department) carried on the planning for the original series of nine units (or courses) in the Highway Technicians Program. Edward Umiker, now associate civil engineer in the Buffalo Regional Office of the Department of Transportation, and Ralph Fimmano, senior civil engineer in the Utica Regional Office, collaborated in developing the topical outlines for the nine units.

The first edition of this Guide (published in 1962) was written by Ralph Fimmano under the guidance of Berton P. Plummer, who was then an associate in the Bureau of Occupational Extension and Industrial Services of the Education Department. Frank E. Howard, former associate in the Bureau of Vocational Curriculum Development and Industrial Teaching Training, also cooperated in the production of the 1962 edition. Mr. Fimmano prepared the major part of the revised edition, while John C. Kacharian, chief engineer, Post Engineer's Office, Watervliet Arsenal, Watervliet, made some additional revisions. E. Noah Gould, associate in the Bureau of Continuing Curriculum Development, supervised the revisions and the final preparation of the manuscript for publication.

To all the agencies and individuals mentioned above this Bureau makes grateful acknowledgment for the responsibilities which they so faithfully fulfilled.

HERBERT BOTHAMLEY, *Chief*
Bureau of Continuing Education
Curriculum Development

H. GEORGE MURPHY, *Director*
Division of School Supervision

MESSAGE TO THE INSTRUCTOR

The rapid expansion in the building of state and Federal highways has caused a serious shortage of qualified technicians and engineers. The New York State Department of Transportation and the State Education Department have collaborated in the Highway Technicians Program to overcome this shortage.

This program is expected to provide the needed technicians and engineers by upgrading people in the lower-level technician jobs. This instructor's guide, *Highway Surveying*, and the others in the program are intended to improve the skills and technical knowledge of those technicians.

Local school districts and other sponsors of adult education programs are being encouraged to offer the courses in this program as part of occupational education. Besides attracting students from the Department of Transportation, students will be drawn from the public works departments of counties, cities, and towns. Employees of construction contractors will also be found in these classes.

Each lesson in this guide includes enough subject matter for about 2 1/2 hours of classroom instruction. The total length of the course, however, may be adjusted to fit the needs of the enrollees.

ROBERT H. BIELEFELD, *Director*
Division of Occupational Education

CONTENTS

		Page
Foreword		iii
Message to the Instructor		iv
Lesson		
1	Introduction to the Course	1
2	The Elements of Surveying	6
3	Measuring Distances	14
4	Leveling	23
5	Leveling (continued)	32
6	Leveling (continued)	42
7	Measurement of Angles and Directions	53
8	The Transit	62
9	The Transit (continued)	74
10	The Traverse and Stadia Surveying	86
11	Principles of Field Astronomy	103
12	Horizontal Curvature	116
13	Vertical Curvature	132
14	The Preliminary, Construction, and Final Surveys	144
	Final Examination	159

ILLUSTRATIONS

Figure		Page
1	Radius of a 1° Curve	118
2	Derivation of Elements of the Simple Curve	119
3	Relationship of Δ, D, and T	120
4	Elements of the Spiral Curve	129
5	The Parabola Used as a Vertical Curve	134
6	Crest Vertical	136
7	Alternate Analysis of the Crest Vertical	137
8	Sag Vertical	138
9	Sag Vertical (Low Point)	140
10	Unsymmetrical Vertical	142
11	Problem Using a *Hold* Control	143

Lesson 1

INTRODUCTION TO THE COURSE

REFERENCES CITED THROUGHOUT THIS COURSE

Davis, R.E., Foote, F.S., and Kelly, J.W. Surveying: Theory and Practice. 5th edition. New York, N.Y. McGraw-Hill. 1966. (Referred to in this unit as "Ref. A")

Bouchard, H., and Moffitt, F.H. Surveying. 5th edition. Scranton. International Textbook Co. 1965. (Referred to in this unit as "Ref. B")

OBJECTIVES

1. To get acquainted with class members
2. To explain the purpose of the course and role of the surveyor in the Department of Transportation
3. To provide a general description of the course
4. To orient the student in several areas of surveying

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. Introduction	Write the name of the course and your name on the chalkboard. Give the students a brief description of your experience.
A. Course purpose	Explain that the course is being given to technicians and to construction inspectors to supplement their knowledge and to assist them in upgrading themselves in their jobs. Add that the course is also valuable training for taking Department of Transportation examinations for engineering positions.
B. Introduction of class members	Have each student introduce himself to the class and give such information as occupation and where employed.
C. Required student equipment	Write the title and author of Ref. A on the chalkboard.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
1. Basic textbook	State that it would be advisable for each student to buy a copy of the book since it is very useful for the course and can also be used in the future. Ask the students to sign a sheet of paper, if they wish, so a group order can be made.
2. Looseleaf notebook	Tell the class that a looseleaf notebook is also needed for course notes.
3. Field notebook	Ask the students to sign a sheet of paper, if they wish, so a group order may be made for a small field notebook.
4. Engineer's scale, protractor, and triangles	Point out that the engineer's scale, protractor, and triangles will be used; small traingles are preferred.
5. Ephemeris	Add that an ephemeris will be provided for each student by one of the surveying equipment companies.
II. Characteristics of a Successful Surveyor	State that technical knowledge and skills are essential in a good surveyor. However, certain traits of character are often more important. A successful surveyor: 1. Believes in and applies the scientific method 2. Is stable, able to control his temper, and is considerate of others 3. Is able to see facts clearly and has sound judgment 4. Has initiative, resourcefulness, and energy 5. Is watchful of the interests of his employer and is respected by his associates

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
III. Course Description	State that only the basic elements of surveying will be covered in this course.
A. Title and brief resume of each lesson	Discuss briefly the content of this course by giving an explanatory statement of the scope and content of each lesson.
1. Introduction	Lesson 1 briefly describes the purpose of the course, and the importance and characteristics of the surveyor. In this lesson the teacher should explain the role of the surveyor in highway planning and construction, stressing his relationship with the Department of Transportation.
2. The elements of surveying	Lesson 2 introduces the student to the concept of surveying. Covered are the various types of surveying, the terminology used, measurements, precision, and errors. Also, the student is given an introduction to the instruments and accessories used.
3. Measuring distances	Lesson 3 discusses the different ways of measuring distances between points on the surface of the earth. Errors and mistakes in measuring are included, along with an explanation of precision and accuracy.
4. Leveling	Lesson 4 describes the leveling process whereby elevations of points are determined. Also covered are descriptions of types of instruments and rods used in leveling, and the important factors of care.
5. Leveling (continued)	Lesson 5 introduces the student to the purposes of leveling in highway engineering. Further, the kind of leveling that is used for each purpose is covered. Described is the procedure for setting up the instruments, taking readings, and use of recorded data.
6. Leveling (continued)	Lesson 6 continues by describing types of leveling and the note-taking process.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	Also, the student is given the methods used in signalling between the instrument man and the rod man. Another segment of this lesson considers the errors that may be encountered in leveling and the adjustments that are to be made to correct the sources of errors.
7. Measurement of angles and directions	Lesson 7 delves into another portion of the surveying responsibility: the measuring of angles and directions. Also, the exact location of any point, line, or survey is determined. The effect of magnetic forces is studied in this lesson.
8. The transit	Lesson 8 describes the construction of the transit in detail. Following this, the mechanics of setting up the instrument are described along with the methodology of measuring angles and laying out lines. Errors resulting from maladjustment are described and a brief mention is made of procedure for running a traverse.
9. The transit (continued)	Lesson 9 continues to discuss the transit and the errors that can occur in its use. Then the numerous procedures for correcting errors are described. Also, in this lesson are the methods for using the transit in field operations: locating lines, running lines, setting lines, application of triangulation, and plotting.
10. The traverse and stadia surveying	Lesson 10 concerns the computation of the traverse, the coordinate system, and the New York State Coordinate System; relationship to geodetic surveying is also included. The other portion of this lesson covers stadia surveying for obtaining horizontal distance and differences in elevation.
11. Principles of field astronomy	Lesson 11 introduces the student to astronomy as used in surveying. This aspect is used in determining latitude, time, longitude, and azimuth.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
12. Horizontal curvature	Lesson 12 familiarizes the student with horizontal curvature and its use in highway alignment. Many of the formulas used in computations are described. Also included are procedural steps for use of the transit on curves.
13. Vertical curvature	Lesson 13 discusses the vertical curve for use in highway alignment. This type of curvature also requires use of various geometrical formulas, described in this lesson.
14. The preliminary, construction, and final surveys	Lesson 14 describes the preliminary, construction, and final surveys for highway systems. The major differences in the procedures for conducting these are covered. Also, discussed are the sequential operations of the three phases.
15. Final examination	A final exam will be given for this course. The examination will highlight student weaknesses. Correcting the test in class and discussing test questions will help strengthen any weak areas. Students will also obtain an evaluation of their interest to continue and progress in surveying.

ASSIGNMENT

In Ref. A read all of Chapters 1 and 2 and pages 72-76 in Chapter 5.

Lesson 2

ELEMENTS OF SURVEYING

OBJECTIVES

1. To provide the student with the concept of surveying
2. To identify and explain terminology used in surveying
3. To acquaint the student with surveying instruments and accessories

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. Definition of Surveying	Define surveying as a system of locating the positions of points on or near the surface of the earth. (Ref. A, p. 1; Ref. B, p. 1) Explain that surveying entails: 1. Measuring horizontal and vertical distances between terrestrial objects 2. Measuring angles between terrestrial lines 3. Determining the direction of lines 4. Establishing points by predetermined angular and linear measurements
A. Scope of this course	State that this course embraces that part of surveying used to prepare plans and profiles for the design and construction of highways and bridges. Point out that the survey process is divided into field work (the taking of measurements) and office work (the mathematical calculations).

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
II. Types of Surveying	
A. Classification based on assumed shape of earth's surface	Explain that one way of classifying kinds of surveying is based on whether the earth is assumed to be a plane surface or a curved surface. This way of classifying divides surveying into *plane* and *geodetic* surveying. (Ref. A, pp. 4-5; Ref. B, p.5)
1. Plane surveying	State that *plane surveying* is the type most often used on construction surveys. In plane surveying: 1. The mean surface of the earth is considered a plane. 2. All level lines are considered to be mathematically straight. 3. All plumb lines are considered to be parallel to each other. 4. Elevations are referred to a spheroidal surface called a datum.
2. Geodetic surveying	State that in *geodetic surveying* the curvature of the earth is taken into account and that: 1. It covers very high-precision surveys which extend over very large areas. 2. If the area is as large as a state, the earth is assumed to be a sphere. If the area is a continent, the true shape of the earth is used.
B. Classification based on purpose of survey	Explain that types of surveying can also be classified on the basis of purpose or method. Each of the seven types of survey in this classification can be applied in both plane and geodetic surveys.
1. Control survey	A survey made to establish horizontal and vertical positions of arbitrary points

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
2. Property survey	A survey made to determine the lengths and directions of boundary lines and the areas bounded by the lines (Ref. A, pp. 7-8)
3. Topographic survey	A survey conducted to determine the configuration of the ground (Ref. A, p. 5)
4. Hydrographic survey	A survey made to determine the configuration of a body of water, including the topography of the shoreline (Ref. A, p. 6)
5. Route survey	A survey to locate a highway, a railroad, a canal, a transmission line, or a pipeline
6. Underground survey	A survey which deals primarily with underground work
7. Photogrammetric survey	Survey using photography to make measurements (Ref. A, p. 7)
III. Terminology	Introduce the special words and expressions which will be used in this course. (Ref. A, p. 9; Ref. B, pp. 4-5)
A. Surfaces, lines and planes	
1. Level surface	A surface parallel to the mean spheroidal surface of the earth
2. Vertical line	A line which follows the direction of gravity at any point
3. Horizontal line	A line tangent to a level surface and perpendicular to a vertical line
4. Vertical plane	A plane which contains a vertical line
5. Horizontal plane	A plane tangent to a level surface
B. Angles, elevation, etc.	
1. Horizontal angle	An angle formed by the intersection of two lines in a horizontal plane
2. Vertical angle	An angle between two intersecting lines in a vertical plane

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
3. Elevation of a point	The vertical position of a point above or below a given surface
4. Difference in elevation between two points	The vertical distance between two level surfaces containing the points
5. Horizontal distance	The distance between plumb lines measured in a horizontal plane
6. Contour line	A line which joins all points of equal elevation on the ground
IV. Measurement and Precision	Mention that surveying entails both *linear* and *angular* measurements. (Ref. A, pp. 9-10; Ref. B, pp. 5-7)
A. Kinds of Measurement	
1. Linear	Feet and decimal parts of a foot are used for linear measurement. Note: On a bridge stakeout, it is often necessary to use fractions of an inch instead of decimals of a foot.
2. Area	Area is measured in square feet and acres. An acre is equivalent to 43,560 square feet.
3. Volume	Volume is computed in cubic feet and cubic yards.
4. Angular	Angles are measured by use of the degree, the minute, and the second.
B. Precision of measurement	Explain that all physical measurements are correct only within certain limits because of errors which cannot be completely eliminated. (Ref. A, pp. 10-11)
1. Degree of precision	State that the degree of precision depends on the instruments and methods used. Note that high precision is desirable, but getting it takes much time and labor. Point out that the degree of precision of a survey should be as high as its purpose justifies.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
2. Errors	State that a surveyor must know the kinds of error, their sources, and their effect upon field measurements. (Ref. A, p. 10; Ref. B, pp. 7-8)
	Point out that the surveyor must know how to keep the magnitude of errors within allowable limits.
	Explain that the measured value of an angle or a distance may approach the true value. This occurs when the number of errors and their size become smaller and smaller as the measurements are repeated.
a. Sources of errors	Mention that errors arise from instrumental imperfections, personal limitations, and natural conditions. (Ref. A, p. 72; Ref. B, pp. 7-8)
(1) Instruments	Point out that an *instrumental* error can be caused by: a tape of incorrect length, an error in the graduations of the circles of the transit or some maladjustment in the level of the transit.
(2) Survey crew	State that a *personal* error is caused by such things as: an observer having difficulty bisecting the target, or reading a vernier exactly, or placing the bubble perfectly on center at the time of a reading. Also, a tapeman may not have the proper tension on the tape. These errors are really caused by human limitations.
(3) Natural conditions	Explain that natural factors such as temperature change, wind, gravity, atmospheric condition, and local magnetism may affect a measurement.
b. Classification of errors	Indicate that an error can be either *systematic* or *random*. (Ref. A, pp. 73-76; Ref. B, p. 7)
(1) Systematic errors	Point out that a *systematic* error always follows some definite mathematical or physical law. Also, that

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	a correction can be determined and applied to the measurement for both magnitude and direction.
	Note that if the cause of an error varies (as with varying temperature) the error is called a *variable systematic* error.
	Add that if the cause of an error does not change, it is called a *constant systematic* error. A short tape is an example of this.
(2) Random errors	Explain that the magnitude and direction of a random error (often called accidental error) cannot be determined. This is because such an error is caused by a combination of factors beyond the ability of the observer to control. The causative factors involved are impossible to correct.
	State that these errors tend to be small. When many measurements are taken, the errors are distributed equally above and below the true value. That is, there are as many measurements greater than true value as there are less than true value.
	Point out that these errors follow the laws of probability. They tend to compensate for each other.
c. Mistakes	Tell the class that a mistake is a personal blunder not an *error*. It is an unintentional fault arising from poor judgment or carelessness. (Ref. A, p. 73; Ref. B, p. 8)
(1) Examples of mistakes	Give the following examples of mistakes: 1. Failure to record each full 100 ft. in taping. 2. Misreading a tape. 3. Reversing digits in a number.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	Impress upon the students that all mistakes can be corrected by a good system of checking.
V. Instruments and Accessories	List the principal instruments and accessories used in surveying. (Ref. A, pp. 13-15, 121-123)
A. Tape, pole, pins, etc.	Explain briefly the construction and uses of the accessories. Pass around each instrument so the students may learn its nomenclature and use.
1. Tape	Describe a *tape* as a graduated, flexible ribbon used for measuring distances. Show samples of both cloth and steel tapes of different lengths; include the reel type and the free type.
2. Range poles	Show steel, wood, and aluminum *poles* and explain their red and white markings.
3. Plumb bobs	Show different weights of *plumb bobs* and demonstrate the insertion of the cord.
4. Compass	Describe the *compass* and explain that it is used only for general orientation.
5. Taping pins or nail hubs	Demonstrate how *taping pins* and *nail hubs* are used for marking off measured distances.
B. Rod, level, and transit	
1. Rod (direct reading leveling rod)	Show the *Philadelphia level rod* and explain how a reading is obtained.
2. Hand level (Locke)	Explain the *hand level*. Point out that this provides no magnification but that it does tell an observer when he is holding it on a level line.
3. Engineer's level	Describe the *engineer's level* as a telescope with an attached spirit level tube, all revolving about a vertical axis. This instrument is mounted on a tripod.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	State that the level is used for determining differences in elevation. The process is called *leveling*.
4. Transit (the universal instrument)	Explain the *transit* as a mounted telescope which may be revolved on either a horizontal or a vertical axis. Tell the class that the transit is used principally for measuring horizontal and vertical angles and for extending a straight line. It is usually equipped with a compass and the entire unit is mounted on a tripod.

QUESTIONS FOR REVIEW

1. Name seven kinds of surveys and briefly describe the purpose of each one.
2. Why is the ordinary construction survey considered to be *plane surveying*?
3. Define *vertical line* and *horizontal line*.
4. What is a *contour*?
5. Without changing your instruments or equipment, how can you increase the degree of precision?
6. Mention two kinds of *personal error*.
7. What is a *conditional error*?
8. Describe the difference between a *systematic* error and a *random* error.
9. Give three examples of *mistakes* as differentiated from *errors*.
10. What type of *linear measurement* is used in surveying?

ASSIGNMENT

In Ref. A read Chapter 3 and pages 115-141.

Lesson 3

MEASURING DISTANCES

OBJECTIVES

1. To describe the different ways of determining the distance between two points on the surface of the earth
2. To provide information on measuring a distance within certain limits of precision
3. To describe the taping method of measuring

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. Methods of Measuring Distances	Explain that the measurement of distance between points on the surface of the earth is one of the main concerns of all surveying. State that there are a number of methods to measure distance, and each has different degrees of accuracy. (Ref. A, pp. 115-120; Ref. B, pp. 9-15)
A. Pacing	Show how any person can measure his natural stride and use the *pacing* system to measure a distance.
B. Use of an odometer	Explain that the *odometer* is a device attached to a vehicle, registering revolutions of a wheel. It can be used to measure distances when a precise measurement is not required.
C. Stadia measurement method	Explain that the upper and lower crosshairs of the transit, level, and alidade are stadia hairs. Distance is indicated by *intercept* between hairs as shown on a graduated rod. Describe briefly the spacing of the crosshairs with respect to a 1-ft. intercept at 100 ft. of distance.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
D. Use of subtense bar	Show on the chalkboard the fundamentals of measuring with a *subtense bar*. Point out that the length of the bar is known precisely. A theodolite or transit is used for the angular measurement and the distance is computed by trigonometry.
E. The Geodimeter	Point out that the *Geodimeter* uses light waves to measure distance. In this method the length of a light wave is the unit of measurement for determining the slope distance between two points. The Geodimeter is an expensive instrument but accurate to 1 part in 100,000. State that the Geodimeter is susceptible to error from stray light and from changes in atmospheric conditions. Measurements with this instrument are most successful at night. Explain that any slope distance measured can be changed to an equivalent horizontal distance by computation.
F. The Tellurometer	Describe the *Tellurometer* as a refined type of radar. List the following facts about this instrument: 1. Accurate to 1 part in 100,000 2. Uses radio microwaves; can be used in light or dark, fog or rain 3. Needs correction for other atmospheric conditions and wave reflections 4. Easily portable
G. Taping (or chaining)	Explain that the surveyor's chain (66 ft.) was once used regularly for surveying. The chain had 100 links, each 7.92 in. long.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	State that the chain is now rarely used but the expression *chaining* is sometimes used to describe the taping procedure.
	Point out that in taping (or chaining) a distance, a steel tape is used which is graduated in feet and decimals of a foot.
II. Measuring Distance With a Tape	Explain that the measuring of distances by use of tapes is an extensively used method.
	Note that the horizontal distance between two points can be obtained two ways with a tape. One, by holding the tape horizontally. Or, by measuring along the sloping ground and applying a correction to the measured distance. (Ref. B, pp. 17-23)
	Tell the class that it is best to use one type of tape in a given survey.
A. Horizontal taping	State that horizontal taping means that measurements are taken directly from the tape as the tape is held in a horizontal position. Computations are not used in this method.
	Explain that the tape is stretched directly on the ground when the ground is level and fairly smooth.
1. Taping on level ground	Demonstrate on the chalkboard how ground features affect taping. These conditions may require that the tape be elevated from the ground the same distance at both ends with the tape held between the waist and knees. (Ref. A, pp. 124-125)
	Show how the tape graduations are projected to the ground with a plumb bob.
2. Taping on uneven ground	Sketch some uneven ground conditions on the chalkboard. Show the way one end of the tape is placed on the ground (at the higher end) with the other end

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	being raised from the ground until the tape is level. This is done either by estimation or the use of a *hand level*. (Ref. A, pp. 126-127)
B. Slope taping	State that slope taping is done by measuring on the ground and then using calculations. Indicate the mathematics involved in reducing a slope measurement to a horizontal distance. (Ref. A, pp. 128-130)
III. Duties of Tapemen (or Chainmen)	Point out that the head tapeman always carries the zero end of the tape.
A. Taping	Describe the procedure for measuring one station, which equals 100 ft. of line. Explain how the rear tapeman aligns the head tapeman. At this point the *alignment* is important to enable the instrument man to set the new line exactly. Tell the students that the proper tension on the tape is either estimated, or gaged with a spring balance. This is always done by the head tapeman. Explain that the rear tapeman plumbs the 100-ft. graduation mark with the plumb bob 1/8 in. above the point. Then the head tapeman clears a small area for the taping pin. Following this, the head tapeman waits for a signal from the rear tapeman and dips the tape about 1/4 in., touching the ground with the plumb bob.
B. Marking and checking	Show how the head tapeman pins the new distance and then checks the location with a second measurement.
C. Taping uphill and downhill	Tell the class how tapemen work uphill and downhill. The head tapeman checks to maintain a horizontal line when the taping operation advances downhill. The rear tapeman checks for horizontal alignment when the taping advances uphill.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
D. Determining station fractions	Explain that when the end of the line is reached, the last distance measured will usually be a fraction of the 100-ft. tape. Describe the method of reading fractions. The rear tapeman holds a full-foot graduation over his point. This particular graduation is the one which will bring the subgraduations at the zero end of the tape over the end-point of the line. The head tapeman then rolls the plumb bob cord along the subgraduations with his thumb until his plumb bob is directly over the end point.
E. Breaking tape	Describe (by means of a sketch) the process of *breaking tape* in making several horizontal measurements on a steep slope or on very uneven ground. Stress the importance of notekeeping to insure that small partial measurements are not lost.
IV. Errors and Mistakes in Taping	Remind the students that (as explained in Lesson 2) inaccuracies in measurement can result from both errors and mistakes.
A. Principal errors in taping (or chaining)	Point out that there are seven principal sources of error in linear measurements made with a tape. These errors, which include both *systematic* and *random* errors, are listed and explained below.
1. Tape of incorrect length	Explain that a tape of incorrect length causes a systematic error. This can be practically eliminated by comparing with the standard tape and applying a correction. Note that the type of error discussed here is *cumulative*. (Ref. A, p. 131; Ref. B, p. 23)
2. Tape not horizontal	Refer to the conversion from slope distance to horizontal distance. Show how the error, when the measuring tape

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	is not horizontal, is equal to $\frac{h^2}{2s}$ where: s = the slope distance between the two given points h = the vertical distance between the two points (Ref. A, p. 131; Ref. B, p. 23) This error is cumulative and always positive. It can be eliminated by use of a hand level.
3. Changes in temperature	State that a steel tape will continually change in length because of *temperature changes*. Discuss *coefficient of expansion* briefly. Demonstrate how a correction is computed by the formula. (In the formula the length of tape, the coefficient of expansion, and the change in temperature are multiplied together.) (Ref. A, pp. 132-133; Ref. B, p. 24) Caution the students that errors due to temperature change are cumulative.
4. Incorrect tension	State that a *tension* error is not of great importance when a reasonable estimate of tension is made. This type of error is negligible except in precise work. Tension can be computed by a formula. (Ref. A, pp. 132, 137; Ref. B, p. 24) Tension errors taken all together tend to be compensating.
5. Sag	Explain that sag affects any measurement where the tape is suspended from the two ends. (The tape assumes the shape of a catenary.) The sag causes the horizontal distance between the two ends to be shorter than the length of the tape. Sag error is cumulative and can be computed by formula. (Ref. A, pp. 132, 135; Ref. B, p. 25)

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
6. Incorrect alignment	Demonstrate the error when one or both of the taping pins are placed on either side of the correct taping line. (Ref. A, p. 131; Ref. B, p. 26) Show how the formula $\frac{h^2}{2s}$ can be used to compute the error when one end of the tape is off line. Mention that this error is cumulative and positive, but almost negligible.
7. Tape not straight	Point out that some parts of the tape may be out of line because of grass or brush in the way. The error caused by this condition is systematic and variable; it is cumulative and positive. (Ref. A, p. 131; Ref. B, p. 26)
B. Other errors in taping	Other errors, which perhaps occur less frequently, are random errors. They include the following (Ref. B, p. 29): 1. Deflection of the plumb bob by wind 2. Failure to place the taping pin on the point where the plumb bob touches the ground 3. Failure to steady the plumb bob
C. Mistakes in taping	Explain that *mistakes* (due to poor judgment or carelessness) which occur commonly in taping (Ref. A, p. 140) include the following: 1. Adding or dropping a full tape length 2. Adding a foot 3. Using the wrong mark on the tape for zero or 100 4. Reading a number wrongly upside down 5. Mentally transposing figures

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	6. Not calling numbers clearly 7. Not calling a decimal point
V. Importance of Accurate Measurements	Tell the class that all efforts should be made to obtain *accurate* measurements. The success of the survey and subsequent application are directly dependent upon accuracy.
A. Precision needed in taping	Point out that accurate measurements are obtained by careful and precise taping, with the proper corrections. Explain the importance of accurate measurements by showing how they will be used. (Ref. A, pp. 138-140; Ref. B, pp. 29-30)
1. Standard tape for correction	Explain that a tape whose actual length differs from its marked length can be calibrated against a standard tape. Each office usually has one standard tape, used for calibration and for no other purpose. When a tape used in actual surveying is compared to the standard, the correction needed is determined. This correction is then applied to all measurements made with this tape. State that accuracy of angular measurement and linear measurement should be compatible. If the angles are roughly measured, it is wasted effort to measure a line to thousandths of a foot.
B. Usual practice in taping	Describe the usual practice in taping through broken country. The procedure is to take measurements with the tape horizontal, break tape, and apply tension by estimation. No allowances for sag or temperature are made.
1. Limits of precision	Explain that although many errors may be made, the more significant errors which commonly occur are: 1. Tape not level 2. Sag in tape

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

3. Variation in temperature

4. Poor plumbing

Assume possible values for the four errors and show that the total error could range from plus 0.44 ft. to plus 0.96 ft. per 1000 ft. of line. This gives limits of precision ranging from 1 part in 2300 to 1 part in 1000.

Note that 1 part in 5000 would be considered excellent taping.

State that the measured length of a line is nearly always considerably longer than the true length.

QUESTIONS FOR REVIEW

1. If the Geodimeter can measure distance so accurately, why is it not used by everyone?
2. How is a tape set horizontally when a measurement is made?
3. How much tension is placed on a standard tape when calibrating another tape?
4. How does an increase in temperature affect the measured length of a line?
5. If a distance is measured with the tape incorrectly aligned, is the error significant?
6. List five mistakes which can be made in taping a distance.
7. What degree of accuracy would be considered excellent taping?
8. How does the measured length of a line compare with the true length in usual practice?
9. Who checks for horizontal when the taping operation advances downhill?
10. In your estimation which of the four common errors is most significant?

ASSIGNMENT

1. Solve problems 1, 2, 3, 6, 7, 13, and 16 on pages 145 and 146 of Ref. A.
2. Read pages 151-173 in Ref. A.

Lesson 4

LEVELING

OBJECTIVES

1. To provide pertinent information about the leveling process
2. To teach the class the use and care of the level

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. Use of Leveling in Surveying	Explain to the class that *leveling* is used to obtain *elevations* of objects in the process of surveying. Leveling is also used to control the grade in construction surveys.
A. Definition	Define leveling as the operation performed to determine the elevation of a point, and the difference in elevation between two points. (Ref. B, p. 32)
B. Curvature and refraction	State that in leveling, the effects of curvature of the earth and atmospheric refraction must be taken into account. (Ref. A, pp. 151-152; Ref. B, pp. 32-33)
1. Effect on leveling	Sketch the earth and show a leveling instrument taking a horizontal sighting. The sketch will show how the *curvature* of the earth affects an elevation. Describe the effect of *refraction* as a downward bent ray of light which counteracts about one-seventh of the curvature effect.
2. Correction formula	Present the empirical formula which corrects for the combined effect of curvature and refraction: $h' = 0.021\ M^2$ where: h' = combined effect of earth's

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	curvature and atmospheric refraction, in feet M = distance from the point of tangency (station of the observer), in thousands of feet
II. Methods of Measuring Elevation	Explain that differences in elevation can be found by barometric, indirect, stadia, and direct leveling. (Ref. A, p. 152)
A. Barometric leveling	Describe briefly how elevation is determined with the aneroid barometer. Critical factors are the sensitivity of the instrument and the complications of the weather. (Ref. A, pp. 156-158; Ref. B, pp. 35-38)
	Point out that barometric leveling is not used in the construction of highways. This method is used mainly on exploratory or reconnaissance surveys where differences in elevation are large.
B. Indirect or trigonometric leveling	State that *indirect* leveling is often called *trigonometric* leveling. Difference in elevation between two points can be determined by measuring the vertical angle from one point to the other and the horizontal distance between them. The difference in elevation is then computed by the use of trigonometry. Sketch an example of this on the chalkboard. (Ref. A, p. 154; Ref. B, p. 33)
1. Correction needed	Remind the class that the effects of curvature and refraction must be corrected when the horizontal distance is more than 1,000 ft. This correction must be applied to readings taken by indirect levelings as well as those taken by some of the other methods.
	Tell the class that this effect can be eliminated by sighting from both ends of the line and using the average of the differences in elevation.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	State that indirect leveling is not used very much in highway work.
C. Stadia leveling	Point out that *stadia* leveling is done with a transit and is a rapid means of leveling. This method is only moderately precise. (Ref. B, p. 35)
	Make a brief comparison between stadia leveling and indirect (or trigonometric) leveling.
D. Direct leveling	Inform the class that *direct* leveling is the most accurate method used to determine the difference in elevation between two points on the earth's surface. (Ref. A, pp. 153-156; Ref. B, p. 34)
1. Application	Draw a sketch on the chalkboard, showing a level set up between points A and B, and discuss the following: 1. Location of the level 2. Reading the rod 3. Difference in rod readings 4. Elevation at B when elevation at A is known 5. Ignoring ground elevation where level stands
2. Demonstration	Set up a level at one end of the classroom and have the students find differences in elevation between various objects. Assign a given elevation to an object and ask the class to compute the elevation of other objects. Stress the fact that this basic operation is the most important element in leveling.
III. The Level	Point out that the *engineer's* level used in the classroom is a typical instrument for leveling.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
A. Description	Indicate that the level consists of a telescope with a very accurate spirit level attached to the telescope longitudinally. (Ref. A, p. 158; Ref. B, p. 38) Show the students that the telescope is supported at the ends of a straight bar, firmly fixed at the center to the axis on which it revolves. This axis and the optical axis of the telescope are perpendicular to each other. The entire level is supported on a tripod.
B. Kinds of levels	Explain that the two main types of level are the *dumpy* level and the *wye* level (also written as *Y-level*). The self-leveling level and the Locke hand level are also used frequently and are discussed below.
1. The dumpy level	Exhibit the dumpy level, pointing out the telescope and its rigid connection to the level bar. (Ref. A, p. 159; Ref. B, pp. 42-44)
a. Description	Name and describe the parts of the dumpy level: 1. Telescope--about 30 or 40 diameters of magnification. The optical axis is perpendicular to the axis of the center spindle. 2. Spirit level--axis parallel to the axis of the telescope. The upper surface of the spirit level tube is round to form a circular curve longitudinally. The sensitivity of the spirit level increases with the radius of the curve. This sensitivity is measured by the angle (given in seconds) through which it must be tilted to make the bubble move one scale division. 3. Cross bar--telescope support

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	4. Capstan-headed screws--used to adjust the spirit level in a vertical direction only 5. Spindle--revolves in the socket of the leveling head 6. Foot plate--threaded to fit the tripod head 7. Clamp--holds the collar on the socket 8. Tangent screw or slow-motion screw 9. Leveling screws--usually four, but use of three is becoming more common 10. Tripod--either fixed or adjustable 11. Sunshade--protects from direct rays of sun 12. Vertical and horizontal cross-hairs--alignment and reading hairs 13. Crosshair adjusting screws 14. Focusing screw and eyepiece
2. The wye level	Show the students the *wye level* and explain the differences between it and the *dumpy* level. (Ref. A, pp. 160-161; Ref. B, pp. 38-42)
a. Differences in construction	The wye level differs as follows: 1. Its telescope can be removed and turned end for end. 2. It has *Y-shaped* supports for the telescope, called wyes. 3. It has capstan-headed nuts to raise and lower the wyes.
b. Advantages and disadvantages	Comparison of the dumpy and wye levels:

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	1. The dumpy level is simple in construction and has few parts. The wye level, however, has the disadvantage of having many parts. 2. The wye level can be adjusted by one man. The dumpy level is at a disadvantage in this respect, since it requires two men for adjustments. 3. The dumpy level requires few adjustments and they last for a longer time. 4. Overall, the dumpy level is the more popular of the two. The wye level is slowly passing out of use in the United States.
3. The self-leveling level	Exhibit a *self-leveling* level and show the class how rapidly it can be set up. (Ref. A, pp. 163-165; Ref. B, pp. 44-45) Point out the bull's-eye bubble (in the circular spirit level) and mention that it centers very quickly. Refer to other characteristics of this level such as its light weight and overall size. Another feature is that it has only three leveling screws.
4. The Locke hand level	Show the *Locke* hand level and allow the students to use it on a 6-foot rule to find eye height. (Ref. A, p. 165; Ref. B, p. 47) Describe the hand level as a brass tube with a small level tube mounted on the top. A 45° mirror enables the user to tell when the main tube is horizontal. Explain that most hand levels do not magnify and can be used only for rough leveling and short distances. Other types are available which magnify 2 or 4 times.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
IV. The Leveling Rod	Tell the class that leveling rods are graduated wooden rods used in measuring differences in elevation.
A. Types	State that there are two types of leveling rod. One is the *target* rod (read by the rodman). The other type is the *self-reading* rod (sometimes called a *speaking* rod) which is read directly by the instrument man. (Ref. A, p. 171; Ref. B, pp. 48-51) Point out that the limit for the accurate reading of a self-reading rod is 400 feet. Beyond this distance a target rod is used.
1. The Philadelphia rod	Exhibit the *Philadelphia* rod and state that it is the most commonly used rod. Describe its parts: 1. Front face and rear face 2. Brass sleeves 3. High and low rod sections 4. Clamp 5. Target Explain the graduations of the rod. Draw a large sketch on the chalkboard showing how readings are made. Mention that the Philadelphia rod can be used both as a self-reading rod and a target rod. Describe the *waving* of the rod and explain its purpose. (Ref. A, p. 172) Pass the target to the students for a close inspection and ask them to note the small *vernier* scale.
a. The vernier	State that the *vernier* is a device for reading a scale to a finer degree than the smallest division on the scale. (Ref. A, pp. 27-29; Ref. B, pp. 51-53)

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	Explain that in the vernier the length of a division is slightly less than a division on the main scale of the rod. Sketch the vernier of the leveling rod target on the chalkboard. Mention that this vernier is 0.09 ft. long and is divided into 10 parts; each part is thus .1 x 0.09 or 0.009 ft. Explain how to read the vernier and give the class printed examples of different readings. Describe *least count* (fineness of reading). (Ref. A, pp. 27-28)
V. Bench Marks	Explain that bench marks are permanent or semipermanent marked points of known elevation. (Ref. A, p. 185; Ref. B, p. 54)
A. Bench mark leveling	State that *bench mark* leveling is determining the elevations of a series of bench marks, placed in the vicinity of a construction project by the survey party.
1. Marking and recording	Point out that a bench mark in the field should always be marked, and should also be described in the notes. Both the bench mark and the notes are valuable for later reference.
2. Coordinating old and new plans	State that if a new system of bench marks is placed, the point of origin should be at a standard, known bench mark. The U.S. Coast and Geodetic Survey has such a system of benches. This system assures that old and new plans for highways and components are on the same *datum*.

QUESTIONS FOR REVIEW

1. Describe the process of leveling.
2. Is it possible that a 1-mile sighting could result in a 3-inch error because of the effects of curvature and refraction?

3. Which type of level is the most popular?

4. Give one distinct advantage of the wye level.

5. Which leveling rod is most commonly used?

6. Why is a target rod used rather than a self-reading rod on a level sighting of more than 400 ft.?

7. Briefly explain the use of a vernier.

8. What is *least count*?

9. Describe a bench mark and explain its use.

10. What is meant by *waving the rod*?

ASSIGNMENT

1. Solve problems 1-6, and 13 on pages 181 and 182 of Ref. A.

2. Study pages 185-197 and 213-227 in Ref. A.

Lesson 5

LEVELING (continued)

OBJECTIVES

1. To study the purposes of leveling in highway engineering
2. To explain and describe the kind of leveling used for each of these purposes
3. To describe the procedures for leveling

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. Leveling in Highway Engineering	State that highway engineering uses survey leveling in numerous phases of design and construction. The main applications are: 1. Establishing bench marks 2. Specifying the profile (the elevation at frequent points) along the centerline of a highway 3. Determining the shape of the ground on both sides of the centerline 4. Delineating the surface configuration of a piece of land
II. Types of Leveling	Explain that the above applications are accomplished by specific types of leveling identified as follows (keyed by matching numbers to paragraphs above): 1. Differential leveling 2. Profile leveling 3. Cross-section leveling 4. Leveling for a plot plan

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

The elevations in all four of these types are usually obtained by *direct leveling.*

A. Differential leveling

Draw a sketch on the chalkboard indicating uneven ground; the examples shown in the textbooks may be used. (Ref. A, pp. 186-189; Ref. B, pp. 57-60) Define *differential leveling* as the operation of determining the elevations of points some distance apart.

1. General steps in leveling

Using the sketch, illustrate the general steps in finding elevations in differential leveling by use of direct leveling:

1. Begin work at a bench mark (whose elevation is known). Record this elevation.

2. From the bench mark, select a point (in the direction the survey is to move) and set up the instrument at that point.

3. Take a reading (called a *backsight*) on a leveling rod at the bench mark. From that reading determine the elevation at the line of sight of the level. This is the *height of instrument* or *H.I.*

4. From the leveling instrument, pick a firm point (a large stone, a concrete object, a tree root) in the direction the survey is to move. This point will be a *turning point* or *T.P.*

5. Take a reading (called a *foresight*) on a rod at the T.P. Determine the elevation of the T.P.

6. Pick another point from the T.P. (in the direction the survey is to go) and move the instrument to that point.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	7. At the new location, take a backsight on a rod held at the T.P. From this reading determine the new H.I. of the level.
	8. Select another T.P. With the level at the same location as in the previous step, take a foresight on the new T.P. and determine its elevation.
	9. Repeat steps 6, 7, and 8 until another bench mark is reached. The elevation shown on this bench mark will provide a check on the steps taken so far.
2. Procedure applicable to other aspects of highway engineering	State that the procedure described above can be continued to determine any number of T.P.'s and bench marks required. It can also be used (with some variation) for *profile leveling*, for *cross-section leveling*, and for leveling a plot plan.
B. Profile leveling	Define *profile leveling* as the process of obtaining the elevations of points along a continuous line. (Ref. A, pp. 213-215; Ref. B, pp. 72-82)
	Note that the principal difference between differential and profile leveling is in the number of foresights and backsights taken.
1. General procedures	Mention that the continuous line followed in profile leveling could be a centerline for a highway, railroad, sewer line, canal, or sidewalk. This centerline may be a straight line, a series of straight lines connected by curves, or a broken straight line. This is sometimes called a *traverse line*.
	Explain that before the elevations of points are determined, the centerline is marked off on the ground. The number of markings depends on the topography of the area. If the terrain is

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	rough the line is marked off in 25-ft. sections; in rolling country, 50-ft. sections; in flat areas, only at full stations, that is, every 100 ft. State that where the slope changes radically, the elevation should be determined at each point of radical change. This should be done even if such a point does not fall on a mark like a 25- or 50-ft. mark. Examples of radical changes in slope are the peak and the bottom of a hill. Draw a sketch on the chalkboard, showing a centerline marked off. This will give an elevation view of the centerline.
2. Field procedures	Outline the steps in the field procedure for profile leveling: 1. Set up the level near the beginning of the centerline. 2. Take a reading on a bench mark and record it. 3. Add the reading to the elevation of the bench mark to obtain the H.I. 4. Take a reading at station 0 + 00 and record it. This is called a *rod reading* or a *rod shot*. 5. Subtract the rod reading from the H.I. to obtain the elevation of station 0 + 00. If 50-ft. marks have been set up on the centerline, the elevation of station 0 + 50 would be the next shot. 6. Continue to take rod shots along the profile until the view is obstructed. 7. Select a T.P. and take a rod reading on it.

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

8. Mark this in the notes as T.P. No. 1 and describe its position.

9. Subtract the reading on the T.P. from the H.I. to establish the elevation of the T.P.

10. Move the instrument along the centerline, back sighting on the rod at T.P. No. 1. Add the rod reading to the elevation of T.P. No. 1 to get the new H.I.

11. Continue finding elevations on points along the centerline until the view is again obstructed.

12. Repeat steps 7 through 11 as many times as needed to complete the profile.

Tell the class that the survey must end at a bench mark so that a check can be made.

State that all rod readings taken on the ground are usually read to the nearest tenth of an inch. Readings taken on turning points and on bench marks are read to the nearest hundredth of an inch.

C. Cross-section leveling

1. Purpose of cross profile

Explain that the DOT design office needs data concerning the shape of the ground on both sides of the centerline. The data is used for location studies and earthwork estimates. *Cross profiles* are run at right-angles to the centerline. (Ref. A, pp. 215-218)

Tell the class that the length of a section in the centerline depends on the topography. A *cross profile* is made at each section mark along the centerline. Thus, if a section is marked every 50 ft., then a cross profile is taken every 50 ft. The cross profile extends to the right and to the left of the centerline.

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

Explain that a modern highway uses a large right-of-way. To get enough width, the cross profile may have to extend as much as 200 ft. to the right and to the left of the centerline.

2. Field procedures

Indicate to the class the field procedure for cross-section leveling:

1. Assume that the 50-ft. points are marked off on the reference line (the centerline, in this case). Set up the level in the vicinity of the beginning station. Find the H.I. by reading a rod on a bench mark and record the H.I.

2. Use a right-angle prism and extend the line at the 50-ft. mark to the right of the reference line.

3. Send the rodman to the right; hold him on line by use of a right-angle prism at the station point. Note that the rodman carries the level rod and the zero end of a 200-ft. cloth tape.

4. Let the tape pass through your hands and read the distance when the rodman stops for an elevation reading.

5. Have the rodman stop for a reading at all changes of slope; (demonstrate with a sketch). The level rod faces to the instrument at every stop. Have the instrument man read the rod and call out the reading. The man at the station point calls out the distance.

6. Tell the notekeeper to record the information at the proper station, under the proper H.I. These notes will be studied in a later session.

7. When enough shots have been taken on the right side of the reference

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	line, repeat the procedure on the left side of the line.
3. Cross-section leveling compared with profile leveling	Compare cross-section leveling with profile leveling. Show that taking a shot at a station point or at zero on the tape is a point on the profile of the reference line. State that when one cross section is finished, the instrument is moved along the reference line to the next section mark. Here another cross section is made.
4. Effect of moving instrument	Tell the class that if a portion of a cross section cannot be made from a given position, the instrument must be moved. The notes must then clearly show that the remaining portion of the cross section was done from a new position. Mention that this work will be reviewed in Lesson 14.
D. Leveling for a plot plan	Explain that for some problems it is necessary to know the *surface shape* of a piece of land. Examples of applications are: drainage, irrigation, earthwork, location and construction of buildings. The procedure for determining surface shape is: 1. Sketch the method of dividing an area. A rectangular grid system is established with distances between lines of 10, 25, 50, or 100 ft., depending on the topography. 2. Stakes are set in the ground at the intersections of the grid lines. Each stake is labeled with a letter and a number. 3. Leveling is done (on the stakes) the same as for profile leveling. Usually more shots are taken from one position of the level than for profile work.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	4. Rod readings are taken at each stake and also whenever a break in the slope of the ground occurs between stakes. The position of each break is measured from the stakes and recorded.
III. Detailed Procedures in Leveling	Explain to the students that the general approach to determining elevations was covered previously in this unit. Additional details necessary for leveling are given below.
A. Setting up the level	State the steps for setting up the level (Ref. A, pp. 171-173; Ref. B, pp. 55-57) as follows:
	1. Spread the legs of the tripod and place them so that the footplate is approximately level. Push each leg firmly into the ground.
	2. Loosen two adjacent leveling screws.
	3. Turn the telescope so it is positioned over a pair of opposite leveling screws.
	4. Adjust the level until the bubble crosses the center of the tube.
	5. Turn the telescope so it is positioned over the other pair of leveling screws.
	6. Bring the bubble to within two divisions of the center.
	7. Repeat the bubble adjustment over the first pair of opposite leveling screws.
	8. Check the bubble for both directions, carefully adjusting one screw for a final position.
	9. Note that when one screw is tightened and the other loosened, the bubble will move in the direction of the tightened screw.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	Caution the students that after the instrument is leveled it should be touched only when necessary. Even walking around the tripod may unbalance the level.
B. Handling the rod	Explain how the rod should be handled: 1. Hold the rod vertically and plumb on the bench mark or the turning point. 2. Place the rod so its face is perpendicular to the line of sight as nearly as possible. Tell the class that a rod that is extended should never be carried about except for immediate use. Always close the rod when there is no need to keep it extended.
C. Reading the rod	Point out the steps for the instrument man in reading the rod: 1. Focus the telescope on the rod. 2. Check the bubble and read the rod. 3. Check the bubble again and record the rod reading. 4. Signal "all right" to the rod man.
D. Bench mark leveling	State that additional details needed for a full understanding of the leveling procedure are as follows:
1. Height of instrument (H.I.)	1. To find the height of the leveling instrument at its first location, add the backsight reading to the elevation of the bench mark. (A backsight is often called a *plus sight*.) In the same way, find the H.I. for any other location of the leveling instrument. This is done by adding the backsight reading to the elevation of the point on which the reading is taken.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
2. Elevation of T.P.	2. To find the elevation of a turning point subtract the foresight (or *minus sight*) from the H.I.
3. Foresight distance to equal backsight distance	3. When determining the location of a leveling instrument or a turning point, make the backsight distance equal to the foresight distance. This procedure will cancel instrument errors. (Ref. A, p. 188)
4. Accuracy assured by rerun	4. To assure accuracy in leveling, make the run over again from the original starting point but use different turning points. Another way is to make the run in reverse.

QUESTIONS FOR REVIEW

1. Explain *differential leveling* and give an example.
2. Describe a turning point.
3. What is a good method of checking a level run?
4. What is profile leveling?
5. In differential leveling how would the lack of a beginning elevation affect the work?
6. When would a grid system for taking level readings be used?
7. What part of cross-sectioning is profile leveling?

ASSIGNMENT

1. Solve problems 13, 14, and 15 on pages 209-210 of Ref. A.
2. Study pages 173-181 and 197-207 in Ref. A.

Lesson 6

LEVELING (continued)

OBJECTIVES

1. To inform the class about a method of notetaking
2. To instruct the class in the use and care of leveling instruments
3. To describe errors in leveling and adjustments on instruments

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. Field Notes	Tell the class that there are various ways to take notes. Show the sample notes in the texts. (Ref. A, pp. 189-191; Ref. B, pp. 60-61)
A. Preliminary survey	
1. Standard system	Describe the system used by the State Department of Transportation. In this system notes begin at the bottom of the sheet and work up the sheet as the stations increase. The notes are usually placed on the left-hand side of the notebook.
2. Bench mark leveling	Pass out prints of a typical *bench mark leveling run* and point out the following facts: 1. The sheet of paper has coordinate ruling and also has six columns for information. 2. The columns, from left to right, are for: station, description, backsight, height of instrument, foresight, and elevation. 3. The point of beginning (B.M. 1) has its description next to it with its elevation in the last column.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	4. Above the first line of information in the third column is the *backsight* (marked, as usual, with a plus sign). Next to it on the same horizontal line in the fourth column is the *height of instrument*.
	5. The first *turning point* or T.P. 1 is found above this line of information with its description in column two. The *foresight*, on the same horizontal line, is in the fifth column (marked, as usual, with a minus sign).
3. Profile levels	State that in the preliminary survey the profile levels are placed in the same type of coordinate notebook as for bench mark leveling.
	Pass out one left-hand sheet and one right-hand sheet, with a typical cross-sectioning problem printed on them.
a. Left-hand sheet	Show how the point of beginning, B.M. 1 (with description), is on the bottom at the left; its elevation is on the right-hand edge.
	Point out that the backsight, marked plus, is shown slightly above and to the right of the notation B.M. 1. The H.I. is in relatively large, heavy figures in the middle of the sheet.
	State that cross-sectioning will begin at station 0 + 00 from this setup of the level.
	Note that the station notations are written on the heavy coordinate lines.
b. Right-hand sheet	Tell the students that the first rod readings for station 0 + 00 will be placed on the right-hand sheet, directly across from the station notation 0 + 00.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	Explain that in the center of the sheet, just below the heavy coordinate line, a zero indicates that a rod reading was taken at the station mark of 0 + 00.
	State that a small dash line over the zero shows the rod reading written on the heavy coordinate line.
	Point out that as rod readings are taken to the right of the base line, the notes follow to the right. The distance from the base line is written *beneath* the coordinate line and the rod readings *on* the coordinate line.
	Add that when the rod readings are taken to the left of the base line, the notes proceed to the left of the zero notation. All rod readings are on the right-hand sheet.
	Explain that there may be a lack of space on the line for the notes, to the left or to the right. If this occurs the station 0 + 00 is continued to one large coordinate square above.
	Tell the students that many stations can be cross-profiled from the same H.I. The H.I. is then carried to the next sheet and written in large, heavy figures at the bottom of the sheet.
4. Reciprocal leveling	Show by sketch how difficult it is to keep the backsights equal to the foresights in leveling across such obstacles as a river or a ravine. (Ref. A, p. 197; Ref. B, p. 68)
	Explain that the difference in elevation is obtained by two sets of observations, one on each side of the obstacle. The mean of the two observations is used.
B. Notes for resurvey work	Mention that after design is completed and just before construction starts, the centerline of the route is established and cross-sectioned.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	Show samples of the hardbound books used for notes.
C. Electronic data sheets	Pass out prints of the new *electronic data sheets*. These show bench mark leveling and profile-leveling information. Explain that these sheets were designed to be used with the Burroughs B-5500 computer. 1. These sheets are used the same as ordinary coordinate sheets. 2. The left side of the sheet has six columns for a level run. 3. If the base line is used, the centerline notation is crossed out. 4. These sheets are weatherproof, strong, reproducible, and concise.
D. Proof of level notes	End a sheet of level notes with the H.I. at the top of the sheet. Begin the next sheet with the same H.I. at the bottom. Show how elevations are checked. The difference in elevation between two bench marks should equal the difference of the sum of the backsights and the sum of the foresights. (Ref. B, p. 61)
II. Signals	Inform the class that the observer and the rodman should always be in constant communication. (Ref. A, p. 39; Ref. B, p. 57)
A. Standard signals	Demonstrate the *signals* used to communicate with the rodman: 1. An upward movement or a raising of the hand signals the raising of the target. 2. A downward movement or lowering of the hand signals a lowering of the target.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	3. A circle of the hand signals clamping of the target.
	4. The signal for plumbing the rod is a raised arm leaning in the direction the rod should go.
	5. A wave of both hands signals "All right."
	6. The observer signals a foresight by holding one arm vertically above his head.
	7. To establish a turning point, the instrument man waves his arm in a circle above his head.
	8. When the rodman is ready to set the rod on a bench or on a turning point, he holds the level rod horizontally over his head. The rod is then brought down on the point.
	9. The signal given to wave the rod is to move one arm from side to side above the head.
III. Errors in Leveling	List the principal sources of errors in leveling on the chalkboard. (Ref. A, pp. 198-201; Ref. B, p. 68)
A. Common errors	1. Instrument defects
	2. Faulty manipulation of level or rod
	3. Errors in sighting
	4. Mistakes in reading the rod
	5. Mistakes in recording or computing
	6. Natural errors
	7. Personal errors
B. Instrument errors	State that there may be numerous instrument errors; the most common one is *imperfect adjustment* of the level.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
1. Imperfect adjustment	Show by sketch the errors caused by imperfect adjustment of the level. Indicate how the balancing of backsights and foresights eliminates the error.
2. Telescope condition	Explain that a *worn telescope* will give faulty readings, especially when the objective lens moves to an inclined position.
C. Manipulation errors	Tell the class that careful instrument users will check the bubble before and after each reading. Demonstrate the possibility of a *high rod reading* being taken. This is caused by the upper section not being completely extended.
D. Settlement errors	Demonstrate on a sketch the error in the foresight if the level tripod settles into the ground between a backsight and a foresight. Point out that the same condition may occur when the turning point is not a solid point.
E. Sighting errors	Explain *parallax*. This is a relative movement of the image of the level rod with respect to the crosshairs as the observer's eye is moved. Stress that this is caused by improper focusing of the objective lens. Let the class observe a fuzzy crosshair and allow the students to adjust the eyepiece until the hairs are clear and distinct. State that the plumbness of the rod can be checked by the vertical crosshair.
F. Mistakes in rod reading	Emphasize that the most common mistake is to misread the number of feet or tenths.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	Call attention to two very common mistakes in recording: transposing figures, and interchanging the backsight with the foresight. Remind the class that only one backsight is ever taken from each position of the level, and that any other reading must be a foresight.
G. Computation	Point out the importance of checking the computations on each page of notes before proceeding to the next page.
H. Errors due to natural sources	Recall the cause of error resulting from *curvature* and *refraction*: 0.002 ft. in a 300-ft. sight.
1. Extreme refraction	Tell the class of the extreme refractive errors that could occur during the middle of a hot day.
2. Precaution against sun	Caution the class to attempt to keep the level shaded. The sun causes uneven expansion of different parts of the instrument which will cause the bubble to move.
I. Personal errors	State that there may be *inherent* conditions in an individual that may cause personal errors. An example is defective vision of the observer which may result in a consistently low or high reading.
J. Limit on errors	State that if care is used in leveling, most of the errors will be *random*. (Ref. A, p. 201; Ref. B, p. 68) Point out that the error in any line is proportional to the square root of the number of setups.
1. Order-of-error formula	List the allowable errors within the specific classifications. The difference in feet between two runs should not exceed a constant times the square root of M, where M is the distance in miles.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	1. First order--allowable error of 0.017 times the square root of M 2. Second order--allowable error of 0.035 times the square root of M 3. Third order--allowable error of 0.05 times the square root of M 4. Fourth order--allowable error greater than the first three Inform the class that running a line of levels for construction work should be at least second order work. For profile leveling 0.1 times the square root of M is generally used.
IV. Adjustments of the Level	Describe the adjustments of the level as being subject to the principle of *reversion*. Reversing the position of the instrument doubles the error. (Ref. A, pp. 173-181; Ref. B, pp. 603-607) Show the capstan-headed screws or nuts which control the crosshairs and those which control the bubble tube. Caution the class to make all adjustments in a careful manner. Repeat all adjustments until the instrument is in satisfactory operating condition.
A. Wye level	Remind the class how the construction of the *wye level* is different from the *dumpy level*. Although the trend is to use the dumpy level, it is best to know the adjustments of the wye level also.
1. Crosshairs	Explain that when the wye level is in adjustment and leveled, the horizontal crosshair should be truly horizontal. The intersection of the vertical and horizontal crosshairs should be a point on the optical axis of the telescope.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
2. Line of sight	Point out that the line of sight of the telescope should be parallel with the axis of the wye rings. This is checked by loosening the clips and sighting a point. If after rotating the telescope 180° in the wyes, the crosshair intersection is still on the point, the telescope is in adjustment. Explain how the upper and lower capstan screws for the crosshairs move the horizontal line for adjustment. Show how the side capstan screws are turned to move the vertical line.
3. The bubble tube	State that the axis of the bubble tube should be in the same plane as the line of sight and parallel to it. Demonstrate this adjustment and show how the level bubble is centered when the telescope is revolved in the wyes. If the bubble is off center, adjust it laterally by means of the capstan screw on the side of one end of the bubble tube. Replace the telescope in its initial position and adjust the leveling screws of the level. If the bubble is off center, make the same adjustment again. Describe the second step by taking the telescope out of the wyes and placing it with the ends reversed. If the bubble is off center, adjust the bubble by means of the capstan nuts at one end of the level tube, until it is halfway to center. Repeat until the bubble remains on center.
4. The wyes	Explain that the reason for adjusting the wyes is to hold the bubble tube perpendicular to the vertical axis of the level. Show that this adjustment requires leveling over one pair of level screws and then over the other pair. The telescope is then revolved 180° on the vertical axis and turned end for end.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	If the bubble is off center, it should be brought halfway back by means of the capstan nuts at the ends of the crossbar. After centering the level again with the leveling screws, the adjustment should be rechecked.
B. Dumpy level	State that there are fewer adjustments on the dumpy level than on the wye level because there are fewer parts.
1. Crosshairs	Point out that the crosshair adjustment is the same as for the wye level.
2. Bubble tube	Explain that the bubble tube adjustment makes the level tube perpendicular to the vertical axis of rotation. This is done so that when the instrument is leveled, the bubble will remain in the center as the telescope is revolved. Show that the bubble tube in the dumpy level is the same as in the wye level with one exception. The capstan screws used on the dumpy level are on the right-hand end of the level tube.
3. Line of sight	Tell the class that the line of sight must be parallel to the axis of the level tube. Describe by sketches the operation called the *peg method*. This is used to test whether the line of sight coincides with the optical axis.
C. Self-leveling level	Note that the only adjustment on the *self-leveling* level is done by the peg method. The horizontal crosshair is moved by means of a single capstan screw. This is hidden from sight under the cap at the eyepiece end.

QUESTIONS FOR REVIEW

1. In leveling why are the backsights marked with a plus sign?
2. In any level run what is the relationship between the difference of any two bench marks and the difference of the sum of the backsights and the sum of the foresights?

3. What is the signal for establishing a turning point?

4. How does a worn telescope affect the accuracy of readings?

5. If 25 readings of a rod are taken from one position of the level, how many of these readings can be backsights?

6. What is the expected error in any line of levels?

7. Construction line levels should be what order of work?

8. What is the principle of reversion?

9. Describe the process of reciprocal leveling.

10. Explain the method by which the line of sight is made parallel to the axis of the level tube.

ASSIGNMENT

1. Solve problems 1-12 on pages 207-209 of Ref. A.

2. Study Chapter 12, pages 254-275 of Ref. A.

Lesson 7

MEASUREMENT OF ANGLES AND DIRECTIONS

OBJECTIVES

1. To provide information on measuring angles and directions
2. To furnish the information for orienting a point, line, or survey

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. Location of Points	Remind the class that the purpose of a survey is to determine the locations of points on or near the surface of the earth. (Ref. A, p. 254)
A. Fixed location	Show that the location of a point is fixed if any one of the following is known: 1. Direction and distance from a known point 2. Direction from two known points 3. Distances from two known points 4. Direction from one known point and distance from another known point
B. Definition of direction	Point out that the *direction* of any line as defined by two points is determined by horizontal angular measurement between the line and some reference line. This applies to a *horizontal projection* (plan view). Add that for *vertical projection* the direction of one point with respect to another can also be defined. The direction is defined by the vertical angle between the plane of the horizon and the line joining the two points.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
C. Definition of an angle	Show that the angle between two points is the horizontal angle between lines passing through the two points and converging at a third point. State that the vertical angle to a point is its angle of elevation or depression from the horizontal. This can be positive or negative.
D. Reference	Explain how lines about a point are referenced to each other. (Ref. A, pp. 254-255)
1. Fixed reference	Point out that a line can be described according to a fixed line of reference (base line). This can be any line of a survey or an imaginary line.
2. Meridian line	Call the fixed line of reference a *meridian*. Describe this meridian as an *assumed* meridian if it is arbitrarily chosen without regard for the compass. Call it a *true meridian* if it passes through the geographical poles of the earth as a true north and south line. Call it a *magnetic meridian* if it is parallel with the magnetic lines of force of the earth. (Ref. A, p. 255; Ref. B, p. 114)
II. True Meridian	Explain that the direction of the true meridian is always the same for any given point on earth. (Ref. A, p. 255) Add that this true meridian is established by an astronomical observation such as a sunshot.
A. Convergence	Tell the class that true meridians on the surface of the earth are lines of geographic longitude. They converge toward the North and South Poles.
B. Amount of convergence	Show by use of a globe that the two factors affecting amount of convergence of two meridians in a given vicinity are: 1. The distance north or south of the equator

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	2. The difference in longitude between the two meridians
C. Grid meridian	State that a *grid meridian* is either assumed or true. This is a reference meridian with which all other meridians in the area are considered to be parallel. (Ref. B, p. 115) Point out the grids on an ordinary geodetic map.
III. Magnetic Meridian	State that the direction of a *magnetic meridian* is that taken by a freely suspended magnetic needle. The direction of the magnetic needle defines the magnetic meridian at a certain location at a specific time. Unlike the true meridian, whose direction is always fixed, the magnetic meridian varies from time to time. (Ref. A, pp. 255-256; Ref. B, p. 114)
A. Variations	Explain that there are many causes for variation in the magnetic meridian direction. (Ref. A, p. 258; Ref. B, pp. 125-128)
1. Change of magnetic pole	Tell the class that there is a continual shift of the earth's magnetic poles. The north magnetic pole is in the vicinity of latitude 74° north, longitude 101° west, in McClintock Sound, north of Hudson Bay, Canada. The south magnetic pole is south of Sydney, Australia, about 1800 miles from the geographical South Pole. The latitude and longitude of the south magnetic pole is 68° south and 144° east; this shows that the poles are not directly opposite.
2. Secular change	Point out that shifting of the magnetic poles causes a *secular change*. This is unpredictable and can be charted only from past performances. Compare the shifting to a pendulum moving from west to east every 150 years and then moving back in the other direction. The greatest speed is in the middle of the cycle.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
3. Annual variation	Add that secular change also creates an *annual variation* which is a minor swing of about 1 minute per year.
4. Local disturbance	Explain that local attraction and disturbances due to geodetic or man-made causes also create variations.
5. Magnetic storms	Tell the class that many factors affect the lines of magnetic force which determine the direction the magnetic needle will take. These are: magnetic storms, sunspot activity, the aurora borealis (aurora australis in the Southern Hemisphere), cosmic ray activity, and ionospheric activity.
6. Erratic action of the lines of force	Remind the class that the needle does not point to the magnetic pole but lines up with the lines of force of the earth. State that on the 100° meridian in the United States, the magnetic pole is due north. However, the compass points 10° or more to the east of true north. Point out the extreme change from Maine, (where the compass points 22° west of true north) to the State of Washington, (where it points 24° east of true north).
B. Magnetic dip	Describe *magnetic dip*, which is 0° at the magnetic equator and 90° at the magnetic pole. (Ref. A, p. 256; Ref. B, p. 123) The magnetic needle of the compass must be counterweighted to offset this effect.
C. Magnetic declination	Define the angle between the true meridian and the magnetic meridian as the *magnetic declination*. (Ref. A, p. 256; Ref. B, p. 125) Use colored chalk and show on the chalkboard the two types of declination. State that if the needle points east of the true meridian, the declination is east. If the needle points

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	west of the true meridian, the declination is west.
D. Isogonic chart	Distribute *isogonic charts* (available from the United States Coast and Geodetic Survey), which show lines of equal declination in the United States for a given year. (Ref. A, pp. 256-257; Ref. B, pp. 126-127)
1. Agonic line	Explain the *agonic line* as the line of zero declination.
IV. Azimuth of a Line	Define the *azimuth* of a line on the ground as the horizontal angle between a meridian and the line, measured in a clockwise direction. (Ref. A, pp. 260-262; Ref. B, pp. 115-116)
A. Basis	Tell the class that in astronomy and in geodetic work the azimuth of a line is measured from the south meridian. In surveying, azimuth is measured from the north meridian. Give examples with line references from true north. Assume a magnetic declination and ask the class to convert the true azimuth to a magnetic azimuth.
B. Forward azimuth	Point out that a stated azimuth is understood to be a line directed from an original point to a terminal point. This is called a forward azimuth.
C. Back azimuth	Explain that if the forward azimuth is under 180°, we must add 180° to find the back azimuth. If the forward azimuth is greater than 180°, subtract 180° to find the back azimuth.
V. Bearing of a Line	State that the *bearing* of a line gives the direction of the line with respect to the reference meridian. (Ref. A, p. 260; Ref. B, pp. 117-118) Repeat to the class that the azimuth of a line is an angle measured in a definite direction from the reference meridian. The angle can run from 0° to 360°.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
A. Size and direction	State that the bearing of a line is never greater than 90°. It indicates whether the angle is measured from the north or south, and whether it is measured toward the east or west. Ask the class what they think a back bearing would be. Give examples of lines and compute both bearings and azimuths.
B. Types of bearings	Add that a bearing may be either true, magnetic, assumed, or grid, depending upon the type of meridian used. Note that when the bearing of a line is north and parallel to the meridian, it is called *due north*. If it is east and perpendicular to the meridian, it is called *due east*.
VI. Relationship Between Bearing and Azimuth	Reiterate that the true azimuth differs from the magnetic azimuth. The difference is the magnitude of the magnetic declination at the time and place of the reading. Explain that if the magnetic declination is east of true north, all magnetic azimuths will be less than corresponding true azimuths by the amount of magnetic declination. If the magnetic declination is west of true north, then the magnetic azimuth will be larger than the corresponding true azimuth by the amount of magnetic declination. Emphasize to the students that conversions between true and magnetic directions are best made by means of the azimuths.
VII. The Horizontal Angle	Define *horizontal angle* as an angle formed by two intersecting vertical planes. The vertical planes intersect along a vertical line which contains the *vertex* of the angle. (Ref. A, p. 264; Ref. B, pp. 131-132)

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	Mention that in surveying, the instrument measuring this horizontal angle occupies the position at the vertex.
A. Direction	Explain to the class that a horizontal angle has a direction or sense. If measured to the right, it is considered clockwise; to the left, counterclockwise.
B. Deflection angles	Explain with a sketch that a *deflection angle* in surveying is the angle made by a foresight with a prolongation of a backsight. (Ref. A, p. 262)
	1. In a closed polygon the algebraic sum of the deflection angles is 360°. This is true when the right deflection angles are considered opposite the left deflection angles.
	2. If the bearing of any line is known and the deflection angles are observed, the bearings of all the lines may be computed.
C. Interior angles	Tell the class that the sum of the interior angles in a closed polygon is equal to 180° (n-2), where n equals the number of sides of the polygon. (Ref. A, p. 262)
D. Traverse	Define a *traverse* as a succession of straight lines connecting a succession of established points along the route of a survey. (Ref. A, pp. 262-263 and 331-338)
1. Traverse features	
a. Transit points	The points defining the traverse lines are called transit points or transit stations.
b. Distance	The distances are measured along the lines.
c. Change of direction	An angular measurement is made at all changes in direction.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
d. Closed traverse	A closed traverse forms a closed figure. This type affords a mathematical check by use of geometry.
e. Open traverse	If a traverse is not intended to close, it is called an *open traverse* or *route traverse*. Also: 1. This is the type used in route surveying or highway work. 2. This traverse is run by measuring angles to the right. An application will be covered in a later lesson. 3. There is no mathematical check on the field measurements. The only checks would be made by tying into another established line or taking a sunshot at the beginning and end of the traverse.
2. Purposes	Point out that traverse surveys are used for many purposes to determine or establish: 1. Positions of existing boundary markers 2. Boundary lines 3. Area 4. Control for mapping 5. Ground control for photogrammetric mapping 6. Control for earthwork problems 7. Control in locating objects

QUESTIONS FOR REVIEW

1. How is *direction* defined?
2. Is the location of a point fixed if distances from two known points are given?
3. Describe a *base line*.

4. What is a *grid meridian*?

5. What causes variations in the direction of a magnetic meridian?

6. Does a compass needle point to the magnetic North Pole of the earth? Explain.

7. What is *magnetic dip*?

8. Differentiate between an *isogonic* line and an *agonic* line.

9. Define an *azimuth* of a line.

10. Compare an *azimuth* of a line with a *bearing* of the same line.

11. In measuring a *horizontal angle*, where should the instrument measuring the angle be located?

12. Describe a *deflection angle*.

ASSIGNMENT

1. Solve problems 1-14 on pages 274-276 of Ref. A.

2. Study Chapter 13, pages 279-295 of Ref. A.

Lesson 8

THE TRANSIT

OBJECTIVES

1. To provide basic information about the construction of the transit
2. To instruct the class on the use of the transit

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. The Transit	Tell the students that the engineer's transit (surveyor's transit) is an instrument of great versatility.
A. Application	Mention that the transit has many uses. It is used to measure and lay off horizontal angles and directions, to measure vertical angles, to determine differences in elevation, and to prolong lines and determine distances. (Ref. A, pp. 279-284; Ref. B, pp. 136-142)
B. Description of the instrument	Point out that this universal instrument has a *telescope* which permits long and accurate sighting. State that the transit has a horizontal *circle* usually graduated in half degrees. High precision work requires graduations of 20' or 15'. Explain that the *verniers* used for reading the horizontal and vertical circles of the transit are based on the same principle as the verniers for the target rod. Add that the *compass box* is used to observe magnetic bearings. Show the *spirit leveling tube* on the telescope. This helps to measure vertical angles accurately and allows the transit to be used as a level.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
C. Parts of the transit	State that the transit is made up of three subassemblies: *alidade*, *horizontal limb*, and *leveling head assembly*. Show pictures or diagrams of the unassembled transit.
1. Alidade	Point out that the *alidade* consists of a circular cover plate equipped with two level vials at right angles to each other. The plate is rigidly connected to a solid conical shaft called the inner spindle. This section also contains the verniers for the horizontal circle, the frames which support the telescope (standards), the vertical circle with vernier, the compass box, and the telescope with its level vial.
2. Horizontal limb	Show that the *horizontal limb* is the middle section which is rigidly attached to a hollow conical shaft called the outer spindle. The outer spindle receives the inner spindle of the alidade. Point out the upper clamp and state that this prevents rotation of the inner spindle within the outer spindle. Also, on the face of the horizontal limb, there is a graduated horizontal circle.
3. Level head assembly	Explain that the piece with the four leveling screws is the *spider* and it holds the outer spindle. Under the spider is the bottom plate which screws on the tripod and supports the leveling screws. Show that the lower clamp prevents rotation of the outer spindle.
D. Functions of transit sections	Indicate that there are essentially three groups of operations in the use of the transit. These affect the telescope, the spindles, and the horizontal circles and verniers.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
1. Telescope	Describe the *telescope* of the transit as being similar to the scope of the engineer's level. It is shorter in length but it has an objective lens, focusing wheel, crosshairs, and eyepiece. (Ref. A, p. 283)
a. Construction	Note that the telescope is attached to the horizontal axis and can be held in any inclination with a vertical clamp. It can be moved slowly in a vertical plane with the vertical tangent screw. Explain that by turning the eyepiece we can regulate the sharpness of the crosshairs.
2. Vertical circle and vernier	Indicate that the *vertical circle* is rigidly connected to the transverse axis of the telescope and that it moves as the telescope is raised or depressed. It may be clamped in a fixed position by its clamp, then moved slowly by its tangent screws. (Ref. B, pp. 141-142) Show that the *vernier* on the vertical circle has a least count of one minute. Explain that the vertical circle should read 0° when the telescope is horizontal. If it does not read 0°, an index error exists which must be accounted for. (Ref. A, p. 296)
3. Spindles	Note that the quality of rotation is what gives the transit its name, a Latin derivative which means *to cross* or *pass over*. Add that the inner and outer *spindles* provide the rotation of the alidade and the limb about the vertical axis of the instrument.
a. Clamped instrument	Point out the status of the transit with both the upper and lower clamps in the clamped position. Neither the alidade which contains the vernier nor the limb which contains the graduated horizontal circle can move.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
b. Upper motion clamp	Explain the status of the transit when the *upper clamp* is locked and the lower clamp is free. The outer spindle is free to rotate and this permits the alidade and the limb to move as one unit.
c. Lower motion clamp	Show the effect with the *lower clamp* locked and the upper clamp loose. The alidade can rotate but the horizontal limb remains fixed. As the alidade with the vernier moves around the edge of the fixed graduated circle, the reading on the circle changes.
d. Slow motion rotation	Inform the class that for slow motion action, both the upper and lower clamps are equipped with tangent screws.
4. Horizontal circle and vernier	Remind the class that the *horizontal circle* is located on the periphery of the upper surface of the horizontal limb. (Ref. A, pp. 284-285; Ref. B, pp. 139-141)
a. Graduations	Show on the chalkboard the different types of graduations such as 30', 20', and 10'. Mention that the circle is numbered both clockwise and counterclockwise so that we can read the angles in either direction.
b. Verniers	Note that on the horizontal circle there are two *verniers* (A and B) exactly 180° apart. Point out the location of the vernier. The outer edge of each vernier is in contact with the inner edge of the horizontal circle.
(1) Vernier design	Remind the class that regardless of shape (either straight or curved) a vernier is always constructed and read in the same manner. Describe the design of the transit vernier as compared to that of the level rod.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	State that the *double vernier* is graduated clockwise on one side for the numbers increasing clockwise and graduated counterclockwise on the other side for the numbers increasing counterclockwise.
	Explain that if the horizontal circle is divided into 30' portions and there are 30 spaces on the vernier, the least count is 30'/30 or 1'. If the horizontal circle is divided into 20' units and there are 40 spaces on the vernier, the least count is 20'/40 or 1/2' or 30".
	Note that the instruments used in the example are 1' and 30" transits respectively.
(2) Reading the vernier	State that any vernier is read by: (1) Noting the graduation on the circle beyond the vernier index (2) adding to the value of that graduation the value of the vernier graduation which coincides with a circle graduation. The reading should always be in the direction in which the circle is increasing.
(3) Class exercise	Ask the students to take vernier readings on the instrument.
(4) Precaution	Caution the class to always use a magnifying glass for vernier readings.
II. Using the Transit	Stress that the basic formation of good working habits will lead to success in the use of the transit. (Ref. A, pp. 290-291; Ref. B, pp. 142-144)
A. Preliminary procedure	Advise the class that all steps in the procedure should be done in the following order. Add that a fixed sequence of operations becomes second nature:
1. Placing the transit on the tripod	1. Adjust the friction of the tripod legs at the tripod head.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	2. Set up the tripod with the legs well spread and pressed firmly into the ground. 3. Place each tripod toe in an indenture or crevice, if on a hard surface. 4. Remove the instrument from the case, lifting it by the base. 5. Remove the dust cap from the objective lens and replace it with the sunshade.
2. Carrying the transit	Hold the transit and tripod on the shoulder in a horizontal position. The instrument should be to the rear, and balanced to carry the weight of the arm.
3. Setting the transit over a point	1. On an incline, stand about 2 ft. downhill, facing the point over which the transit is to be set up. 2. Seize two legs and place the third leg on the ground about 2 ft. uphill from the point. 3. Pull the other two legs outward and backward. Place legs on the ground so the footplate is nearly level. 4. If the ground is level, the legs are spaced equidistant from the point so the footplate is nearly level. 5. Attach the plumb bob to the hook of the instrument by using a sliding knot in the cord. (Draw a sketch of the sliding knot and show the class how to tie it.) 6. Center the instrument on the footplate.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	7. Move the instrument without changing the relative position of the tripod legs so the plumb bob hangs within 2 or 3 in. of the point.
	8. Push each leg firmly into the ground.
	9. Raise or lower the plumb bob until it hangs about 1 in. above the point.
	10. Choose the leg that is most nearly on the opposite side of the point from the plumb bob. Push this leg farther into the ground or move it outward and then push it into the ground, until the plumb bob is exactly opposite a second leg.
	11. Move the second leg until the plumb bob comes within 1/4 in. of the point.
	12. Loosen two adjusting screws. This loosens all leveling screws.
	13. Level the instrument roughly without setting the screws tighter.
	14. Turn the instrument until the plate levels are in line with pairs of opposite leveling screws. Turn the leveling screws.
	15. Slide the head until the plumb bob is over the point.
	16. Level the instrument by gradually tightening the leveling screws.
4. Precautions	Stress the importance of not touching the instrument after it has been set up, except to operate it.
B. Measuring a horizontal angle	Explain that when measuring a *horizontal angle* both the upper and lower clamps are loosened and the horizontal limb

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	rotated. The standards are held until the zero graduation on the circle is almost coincident with the index of the vernier. (Ref. A, pp. 291-292; Ref. B, pp. 144-145)
1. Setting the "A" vernier at zero degrees for convenience	State that the *A vernier* can be set at zero by clamping the upper motion and turning the upper tangent screw to make the zero graduation with the vernier index. The vernier nearest the upper clamp and tangent screw is known as the *A vernier*.
2. Pointing the instrument	Mention that in pointing the instrument only one horizontal clamp is free. The lower clamp is free when starting to point on the first side of the angle and the upper clamp when pointing to the other side of the angle. Remind the class that the lower motion is free so the telescope can be aimed at the first *range pole*.
a. The backsight	State that to make the backsight, the lower motion is clamped and the objective lens is focused. The vertical crosshair is then brought on the sight rod with the lower tangent screw. Note that the instrument is now completely locked and the circle reading is 0° and 0'.
b. The foresight	Inform the class of the procedure for making the foresight: 1. Loosen the upper clamp and rotate the alidade clockwise on its vertical axis until the telescope is aimed at the second sight rod. 2. Clamp the upper motion and bring the vertical crosshair in on the rod with the upper tangent screw.
c. The angle	State that the angle turned is now on the horizontal circle, which is the difference between the initial reading of zero and the final reading.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
3. Synchronization of lines and planes	Describe the various components of the transit as lines and planes (Ref. B, pp. 145-147): 1. The line of sight is normal to the horizontal axis. 2. The horizontal axis is normal to the vertical axis. 3. The vertical axis is normal to the plane containing the horizontal circle. 4. The line of sight is parallel to the axis of the telescope bubble tube. 5. The axis of the plate levels lie in a plane parallel to the horizontal circle. 6. The optical center of the objective lens is parallel to the line of sight. 7. The inner spindle and outer spindle must be concentric. 8. The horizontal circle and verniers must be concentric. 9. A line joining the indices of the A and B verniers must pass through the center of the horizontal circle.
4. Maladjustment of the transit	Caution the class that a transit is never in perfect adjustment. There is always some adjustment required. (Ref. B, pp. 145-148)
a. Methods of reducing error	State that there are two methods that we can use to eliminate errors caused by maladjustment: *double-centering* and *reading* both the *A* and *B verniers*.
(1) Double-centering	Advise the class that of the two corrective methods double-centering is more important. This method is also

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	called *double-sighting*. (Ref. A, p. 296; Ref. B, pp. 145-146) Describe double-centering as the procedure of making a measurement of an angle once with the telescope in an erect position and once with the telescope in the inverted or *plunged* position. The mean value of the readings is used. Point out that *plunging the telescope* is the act of turning the telescope about its transverse axis. The telescope bubble vial is on top of the telescope. Stress that double-centering eliminates personal errors and instrumental errors and increases the accuracy of the measurement.
(2) Angles by repetition	Tell the class that we can also reduce errors when measuring angles, by repetition. Half of the readings are made with the telescope plunged and the mean value of the readings is used. (Ref. A, pp. 292-295)
C. Running open traverse	Draw a sketch on the chalkboard of a base line run and letter the transit points, starting with A. Describe to the class the steps involved in running an open traverse: 1. Assume that the line AB, the first leg of the base line, has a magnetic azimuth or a true bearing (by solar observation). 2. Set up the transit at B and backsight at A with the horizontal circle set at zero. The lower motion should be clamped and upper motion free. 3. Turn a clockwise angle to C, and take the first reading. Lock the upper motion, releasing the lower motion.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	4. Plunge the telescope and backsight at A. 5. Release the upper motion and clamp the lower motion. Turn clockwise to C, taking the second reading; this is cumulative. 6. Move the telescope to the erect position, lock the upper motion. Release the lower motion, and backsight at A. 7. Turn the telescope clockwise to C, taking the third reading (cumulative). Plunge the telescope and backsight at A. 8. Release the upper motion, clamp the lower motion, turn clockwise to C. Take the last and fourth reading. 9. Divide the four readings by 4 and use the mean value.
1. "Angles-to-the-right"	Label the above method (an open traverse) *angles-to-the-right*. This expression is used by the New York State Department of Transportation.

QUESTIONS FOR REVIEW

1. Name the three subassemblies of the transit.
2. Describe the *alidade*.
3. How is the sharpness of the crosshairs regulated?
4. When the *lower clamp* is locked, what portion of the transit is immobilized?
5. Explain *index of error*.
6. When the *upper clamp* is locked and lower clamp is free, what motion is possible in the transit?
7. What is the least count if the *horizontal circle* is divided into 20' units and there are 30 spaces on the vernier?

8. Describe briefly how the *sliding knot* is made.

9. Explain briefly the procedure for measuring an angle.

10. What is meant by *plunging the telescope*?

11. Why are angles measured *by repetition*?

12. What is the most important rule to remember when reading a *vernier* on the horizontal circles of the transit?

ASSIGNMENT

1. Solve problems 1-4, 7, and 8 on pages 320-321 in Ref. A.

2. Study Chapter 13, pages 298-320, and Chapter 14, pages 326-347 in Ref. A.

Lesson 9

THE TRANSIT (continued)

OBJECTIVES

1. To describe sources of errors in angles
2. To teach the adjustments of the transit
3. To describe field operation with the transit

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. Sources of Errors in Transit Angles	Describe the sources of errors as being instrumental, personal, or natural.
A. Instrumental errors and corrections	Note that all *instrumental* errors are systematic. (Ref. A, pp. 312-317; Ref. B, pp. 154-157)
1. Errors in measurement of angles	Point out that when the line of sight is not parallel to the telescope level, an error is introduced in the measurement of vertical angles. Show that this error is eliminated by reading a vertical angle with the telescope direct and reversed. This procedure also eliminates any error arising from the displacement of the vertical circle vernier from its correct position. Tell the class that most instrumental errors can be eliminated by taking the mean of two angles. One observation can be made with the telescope direct and the other with the telescope inverted. The following are examples of possible errors: 1. The optical axis of the telescope should be parallel with the movement of the objective lens when it is being focused. If this condition does not exist an error

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	will be introduced in the measurement of a horizontal angle. This will be especially true when the backsight or foresight stations are at different distances from the transit. 2. The line of sight must be perpendicular to the horizontal axis of the transit. If not, an error will be found when the backsight and foresight points are at different elevations. 3. The horizontal axis must be perpendicular to the vertical axis. If not, an error is created when the backsight and foresight points are at different elevations. Mention that if the plate bubbles are out of adjustment, the vertical axis is not truly vertical when the bubbles are centered. Eliminate this error by leveling both bubbles, turning the telescope 180° and bringing both bubbles halfway back to center.
2. Error of eccentricity	Note that the A and B verniers should be 180° apart. If they are not, a reading should be made on both verniers and the mean value used.
B. Personal errors	State that *personal* errors are introduced by the instrument man and his rodman. These are always more serious when short sights are used; they are cumulative. Some causes of personal error are: (Ref. A, pp. 317-318; Ref. B, pp. 156-157) 1. Failure to have instrument centered over station point 2. Bad pointing of the telescope on the target 3. Failure to give sight exactly on point

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	4. Failure to use a magnifying glass on the vernier 5. Imperfect focusing of the telescope 6. Failure to center the plate bubbles exactly
C. Natural errors	Describe *natural* errors as being due to weather or soil conditions (Ref. A, pp. 318-319): 1. Wind vibrating transit or swinging plumb bob 2. Heat from the sun causing unequal expansion of parts 3. Settling of tripod legs due to boggy ground or thawing soil 4. Refractive errors due to atmospheric conditions
D. Errors not otherwise classified	Point out that there are personal mistakes not classified as personal errors. These are blunders and are called *busts* in the field. (Ref. B, pp. 157-158): 1. Forgetting to level instrument 2. Turning the wrong tangent screw 3. Transposing digits in recording 4. Dropping full 20', 30', or 40' from a vernier reading 5. Reading the wrong circle 6. Recording a small vertical angle with the wrong algebraic sign 7. Sighting on the wrong target
II. Precision of Angular Measurements	Note that the accuracy required in the measurement of horizontal angles is largely determined by the purpose of the survey. (Ref. A, pp. 319-320; Ref. B, pp. 170-173)

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
A. Allowable angular error	Explain that if the *allowable linear error* in a distance L is d, the corresponding angular error, e, can be computed from the relation: $\tan e = \frac{d}{L}$
1. Results desired	Show that when distances are measured to 1/500, the angles need only be measured to 5'. If distances are measured to 1/5000, the angles need only be measured to 30". And if distances are measured to 1/10,000 the angles need only be measured to 20".
2. Probable error	Note that the *probable error* in the direction of any line in a traverse, with respect to any other line, may be expected to vary as the square root of the number of setups between the two lines.
3. Indeterminate precision	Remind the class that unless a traverse is closed or begins and ends at known points, the precision is indeterminate. If proper procedures are followed, there will be reasonable assurance that the accuracy will not fall below a fixed standard.
4. Limits for traversing	Explain that in highway work the required precision must have imposed limits. The *angular error of closure* should not exceed 30" times the square root of n, where n is the number of observations. The total *linear error of closure* should not exceed 1/5000.
III. Adjustments of the Transit	State that in order for a transit to function properly and accurately it must be kept in perfect adjustment at all times. (Ref. A, pp. 307-310)
A. To eliminate parallax	Describe the procedure for eliminating *parallax* (Ref. B, p. 608): 1. Sight through the telescope and focus the eyepiece on the cross-hairs.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	2. Focus objective lens on a clearly defined target about 300 ft. away. 3. Turn the objective focusing pinion slowly backward and forward, at the same time moving your eye from side to side. 4. Observe for apparent lateral movement between the image and the crosshairs. 5. Stop focusing at the point where no lateral displacement occurs. Disregard sharpness of image and crosshairs as this is the point of no parallax. 6. Refocus the eyepiece if the image is not sharp. It will be found that the crosshairs will be more distinct.
B. To make the vertical crosshair perpendicular to the telescope axis	Note that the *line of collimation* is the optical line of sight passing through the optical center of the lens and the intersection of the crosshairs. To make the vertical crosshair perpendicular to the telescope axis do the following (Ref. A, p. 307): 1. Sight through the telescope and set one end of the vertical crosshair on a sharply defined point, A. 2. Elevate or depress the telescope so the vertical crosshair traces over the point. 3. If coincidence is not present, loosen all four capstan screws on the crosshair ring. 4. Move the crosshair ring around in the proper direction. Check and continue to adjust until the vertical crosshair is in exact coincidence with a point, as the telescope is moved up and down.

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

5. Tighten the capstan screws and check again.

C. To make the plane of collimation of the vertical crosshair perpendicular to the telescope axis

Describe the procedure for making the *plane of collimation* of the vertical crosshair perpendicular to the telescope axis (Ref. A, pp. 310-311):

1. Set up the transit and sight the vertical crosshair on point A, about 300 ft. away from the transit.

2. Plunge the telescope and set point B at approximately the same distance away from the transit.

3. Leave the telescope in the plunged position and rotate the instrument to sight again on A.

4. Plunge the telescope and set point C along the same line as points A and B. This point will not fall on point B if the instrument is off adjustment.

5. Take one-quarter of the distance from points B to C and set point E on the same line.

6. Turn the horizontal screws on the crosshair ring until the vertical crosshair is set on point E.

7. Set on A and repeat operations until points B and C coincide.

D. To make telescope axis perpendicular to vertical axis or spindle

Describe the procedure for making the telescope axis *perpendicular* to the vertical axis, or spindle (Ref. A, pp. 308-309):

1. Set up the transit and sight on high point A.

2. Depress the telescope and set point B on the ground.

3. Rotate the instrument 180° and sight back on A.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	4. Depress the telescope again and set point C. 5. Take one-half of the distance from points B to C and set point D so that BD is equal to DC. 6. Raise or lower the right end of the telescope axis until the vertical crosshair intersects point D.
E. To make axis of telescope level parallel to the line of sight	Explain that making the axis of the telescope level *parallel* to the line of sight requires the same adjustment as for the dumpy level. (Ref. A, p. 310) Proceed with this check, using the two-peg adjustment. Note that when the line of sight is set on the proper rod reading, the correction is made by raising or lowering one end of the level tube until the bubble is centered.
F. To make the plate bubble tube axis perpendicular to the vertical axis or spindle	Describe the procedure for making the plate bubble tube axis perpendicular to the vertical axis or spindle (Ref. A, p. 308): 1. Set up the transit. Rotate the transit plate so each bubble tube is over a pair of leveling screws. 2. Bring the plate bubbles to the center of both tubes. 3. Turn the plate 180° in azimuth. 4. Note how far the bubbles move from the center. 5. Raise or lower the tube until the bubbles come halfway back to center. 6. Repeat until turning the instrument in any direction will not affect the bubble tubes.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
G. To make vertical circle read zero when line of collimation is horizontal	Describe the procedure for making the vertical circle read zero when the line of collimation is horizontal (Ref. A, p. 310): 1. Level up the transit using the telescope level. 2. Inspect the vernier and vertical circle to see if the zeros coincide. 3. If they do not coincide, loosen screws and shift vernier until the zeros do coincide.
IV. Field Operation with Transit	Tell the class that many *field operations* are performed with the transit.
A. Prolonging a straight line	Show how prolonging a straight line involves the simple procedure of plunging the telescope. (Ref. A, p. 298) Point out that if the instrument is out of adjustment, the method of double-centering must be used. (Ref. B, p. 183)
B. Balancing-in	Define *balancing-in* as the procedure used when two ends of a line are not intervisible but both ends can be seen from an intermediate point. (Ref. A, p. 302; Ref. B, p. 185) Show by sketch that the instrument is set at the intermediate point, sighted at A, plunged, and sighted at B. Explain that the distance between the foresight and point B is estimated. The instrument is set up a proportional distance from the two points in an effort to be on the line. This is repeated until the instrument can be placed exactly on the line by sliding the transit on the footplate.
C. Running random lines	Show on the chalkboard the procedure if point B is not visible from point

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	A or from any intermediate point. A random line may be run from point A to a point where point B may be seen. (Ref. A, pp. 302-303; Ref. B, pp. 185-186)
	Indicate that the angle between the random line and AB can be computed by trigonometry.
D. Finding the intersection of two straight lines	Explain by use of a sketch that the *intersection* of two straight lines is found by using straddle stakes and string. (Ref. A, p. 304; Ref. B, pp. 186-187)
E. Prolonging a line past an obstacle	State that obstacles such as heavy timber, houses, or buildings which cannot be removed until construction begins prevent direct extension of a line. We can, however, use methods to overcome the obstacles.
1. Offset method	Describe the *offset line*. This utilizes a perpendicular offset distance from the line, a right angle turn which places the line parallel to the original line, and a perpendicular offset back to the original line. (Ref. A, p. 300; Ref. B, pp. 187-188)
	Note that short sights are critical and difficult to use in this procedure.
2. Deflection angle method	Point out that another method utilizes an *isosceles triangle*. In this triangle we use small base angles and even-foot legs. (Ref. A, p. 301)
	Show that when an obstacle is encountered, a small deflection angle (α) is turned off the desired line. Then an even numbered distance (such as 100 ft.) is taped.
	1. Set transit at the 100 ft. mark. Turn a deflection angle (2 α) in the opposite direction.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	2. Measure the same distance (100 ft.) on this line, establishing a point on the original line.
F. Setting parallel lines	State that the offset principle can be used to set two lines *parallel* to each other. (Ref. B, p. 188)
	Tell the class that two offsets are geometrically sufficient but that three offsets are desired.
	Stress the use of geometry. Show that parallel lines can be set by making the alternate interior angles equal.
G. Measuring an angle when transit cannot be set at the vertex	Explain that it is sometimes impossible to set the transit at an intersection of building walls or fence lines. (Ref. A, p. 305)
	Sketch an intersection of fence lines and show how offset lines to each fence are set by *swing offsets*.
	Point out that the transit is placed at the intersection of the offset lines and the angle is turned between the offset lines.
H. Application of triangulation	Explain the process of determining an inaccessible distance (such as across a body of water) by the use of trigonometry. (Ref. A, p. 304)
1. Solving with trigonometric tables	Show that with two setups of the transit, two angles are measured and one distance taped. This enables the unknown side to be computed by the use of trigonometric functions.
2. Solving without trigonometric tables	Mention that if tables are not available, a second method may be used which involves simple arithmetic.
	Show by sketch the layout of two similar triangles. Turn a 90° angle from the inaccessible point to a point on the working side of the obstacle. (See sketch in Ref. A, p. 304.) No.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	other angles are turned but two measurements are made.
I. Plotting by radiation	Describe plotting *by radiation*. This is a procedure in which the transit is set up at a convenient point and the horizontal angle and distance to each desired object is observed. (Ref. A, p. 329)
J. Plotting by intersection	Emphasize the importance of intersection in connection with the location of objects which must be defined accurately. (Ref. A, p. 330) Explain the procedure of plotting *by intersection*. This method uses a base line or any convenient line of a known distance. Angles to the objects are observed from both ends of the base line. Add that the base line becomes the known side of a triangle. The object is at the vertex of the triangle, and both measured angles adjacent to the base line are known. Point out that the triangles can be computed for distances which are necessary for plotting. Caution the class that well-shaped triangles should be used with reasonably sized angles.
K. Plotting by resection	Describe this variation of intersection. This is a method of setting the transit in an unknown location and determining the location of the transit by sighting on points of known location. (Ref. A, p. 331)

QUESTIONS FOR REVIEW

1. Name three sources of error which may occur in the use of the transit.
2. How are most *instrumental* errors eliminated?
3. How is an error of *eccentricity* eliminated?

4. Give three types of *personal* errors which are prevalent in the measurement of angles.

5. List three types of *natural* errors which could affect the measurement of angles.

6. What is the *probable* error in the direction of any line in a traverse with respect to any other line in the same traverse?

7. What is allowable in highway work with respect to the *angular error of closure*?

8. What is allowable in highway work with respect to the *linear error of closure*?

9. Describe *parallax*.

10. Explain the position of the *line of collimation* in the telescope.

11. Why is the *two-peg test* made?

12. What is the procedure of *balancing-in*?

13. How can a line be prolonged past an obstacle?

14. Describe how an angle may be measured when the transit cannot be placed at the vertex of the angle.

15. Differentiate between the procedures of *radiation* and *intersection*.

16. In using the *principle of resection* what factor is not known?

ASSIGNMENT

1. Solve problems 9-19 on page 321 of Ref. A.

2. Study Chapter 13, pages 295-298; Chapter 15, pages 350-375; Chapter 16, pages 415-417; and Chapter 18, pages 454-461, all in Ref. A.

Lesson 10

THE TRAVERSE AND STADIA SURVEYING

OBJECTIVES

1. To teach the computation of the traverse
2. To show how to use the State Coordinate System
3. To introduce the fundamentals of stadia surveying

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. The Traverse	Point out to the class that while the *open* traverse provides no mathematical check on field measurements, the *closed* traverse does follow the laws of geometry. (Ref. A, pp. 331-334; Ref. B, pp. 192-194)
A. Traverse construction	State that a traverse may be run: 1. By design (a perimeter of a given area) 2. By coincidence (intersections of base lines and sidelines of open base line surveys) Show how a certain base line could be run with sidelines that leave the base line at some point and then return at some other point. This provides *closure*.
B. Interior angle traverse	Explain that in the *interior angle traverse* the interior angles and horizontal distances are first measured. Then a check is made with the formula $180° (n-2)$ on the sum of the angles. (n is the number of sides of the traverse.) (Ref. B, pp. 194-197)
1. Angular error	Point out that in a traverse of n sides there is a limit on the closure of the measured angles. This should not

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	exceed the least count of the vernier of the transit times the square root of n.
2. Bearings	Mention that only one azimuth may be known at the beginning of the traverse. Check the students' knowledge about determining the azimuths for all the lines in the traverse and for converting them into bearings.
C. Deflection angle traverse	Show by sketch the *deflection angle traverse* that closes on its point of origin. (Ref. A, pp. 334-335; Ref. B, pp. 197-202)
1. Angular error	Mention the check for *angular error* that must be made before the bearings are computed for the sides. The difference between the sum of the right deflection angles and the sum of the left deflection angles must equal 360°.
D. Adjustment of angular error	Repeat that by using the formula 180° (n-2) the total error in angles may be found for any closed traverse. (Ref. B, p. 195)
1. General distribution	Indicate that since all angles are measured under similar conditions, the usual procedure is to *distribute* the total error *equally*. (Ref. A, pp. 458-459) Stress that distribution is done immediately after discovering the total angular error and before any other adjustment is made.
2. Other distributions	Add that judgment may be used in distributing total angular error. If some angles are measured between very short sides, the error may be within those angles. Describe distribution if repeated measurements yield angles above the accuracy of the instrument, such as

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	readings to 20" on a 1' transit. The error may be distributed within those arithmetically derived angles.
E. Traverse computation	Emphasize that the result of the field work in executing a traverse is a series of connected lines of known direction and length. (Ref. B, pp. 209-210)
1. Distribution of total error	Note that the first step in the traverse computation is the distribution of the total angular error.
2. Computation of bearings	Tell the class that bearings are next computed so that each line has a direction relative to the others.
3. Linear errors	Point out that errors may exist in the measured lines which would tend to alter the shape of the traverse. A system of *latitudes* and *departures* is used to discover discrepancies.
4. Adjustment of the traverse	State that after the latitudes and departures are computed, the error of closure is found and the survey is balanced.
II. Rectangular Coordinates	Describe the coordinate axis for any line as a reference meridian (true, magnetic, or assumed). Also, describe a line at right angles to the meridian as a reference parallel. (Ref. A, p. 454)
A. Origin	Show that the intersection of these lines marks the *origin* and that any bearing may be plotted in its proper quadrant.
B. Projections	Explain what is to be done when the length and direction of a line are known. The length of its *orthographic projection* upon the meridian and upon the parallel is computed. (Ref. A, pp. 455-456; pp. 210-211)
1. Latitudes	Show that the projection of a line AB on the meridian is termed the *latitude*

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	of the line. This is found by multiplying distance AB by the cosine of the bearing angle.
	Note that if a line has a northerly bearing, its latitude is designated as north, or positive. If the line has a southerly bearing, its latitude is designated as south, or negative.
2. Departures	Show that the projection of a line AB on the parallel is called the *departure* of the line. Departure is found by multiplying AB by the sine of the bearing angle.
	Note that if a line has an easterly bearing, its departure is designated as east, or positive. If the line has a westerly bearing, its departure is designated as west, or negative.
C. Computations	Emphasize that in computing a traverse, care must be exercised to work systematically.
1. Data form	Draw the form used for computation on the chalkboard and give the class a simple example with four courses. (Ref. B, p. 212)
2. Class problem	Work out a problem on the chalkboard. Emphasize the observance of signs and the placement of the proper function of each angle in its proper position.
	Set up the problem so that errors are incorporated. For example, the latitudes and the departures can contain a difference in their plus and minus sums. Elicit the necessary corrections from class members.
D. Summation of latitudes and departures	Indicate that in any closed traverse the sum of the north latitudes should equal the sum of the south latitudes. Also the sum of the east departures should equal the sum of the west departures. (Ref. B, pp. 213-216)

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	Tell the class that there is no possible means of determining the true magnitude of angle and distance errors which occur throughout the traverse.
	State that some surveyors wrongly distribute the error in accordance with their own estimation of the field conditions. There are several rules for distribution of errors which will produce a *mathematically* closed diagram.
1. Compass rule	Explain that in order to reconcile any adjustments in the measurements of a survey some assumptions must be made. (Ref. A, pp. 459-460; Ref. B, p. 217)
a. Errors	1. The errors in traversing are accidental and, therefore, vary with the square root of the lengths of the sides. This makes the corrections to each side proportional to its length.
	2. The effects of the errors in angular measurement are consistent with the effects of errors in taping.
b. Definition	Define the compass rule:
	1. Latitude of any course: $\frac{\text{correction to be applied}}{\text{total correction in latitude}} = \frac{\text{length of course}}{\text{length of traverse}}$
	2. Departure of any course: $\frac{\text{correction to be applied}}{\text{total correction in departure}} = \frac{\text{length of course}}{\text{length of traverse}}$
2. Transit rule	Explain the assumptions on which the transit rule is based (Ref. A, pp. 459-460; Ref. B, p. 217):

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	1. The errors in traversing are accidental.
	2. The angular measurements are more precise than the taping measurements.
a. Definition	Define the transit rule as follows (Ref. A, p. 459):
	1. Latitude of any course: $\frac{\text{correction to be applied}}{\text{total error in latitude}} = \frac{\text{latitude of course}}{\text{arithmetical sum of all the latitudes}}$
	2. Departure of any course: $\frac{\text{correction to be applied}}{\text{total error in departure}} = \frac{\text{departure of course}}{\text{arithmetical sum of all the departures}}$
	Note that the transit rule is merely a rule of thumb which does not apply successfully in all cases.
3. Problem	Use the compass rule on the sample problem used to demonstrate how to compute latitudes and departures and then balance the survey.
	Show how the length of each side and its bearing is adjusted.
III. Location by Rectangular Coordinates	Amplify the previous explanation of rectangular coordinates. Describe the coordinates of a point as the distances measured to the point from a pair of mutually perpendicular axes. (Ref. A, pp. 454-455; Ref. B, pp. 221-222)
A. Axes	State that the distance from the X-axis is the Y coordinate of the point. The distance from Y-axis is the X coordinate of the point.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
B. Plane surveying	Mention that in the United States the north part of the meridian on which the survey is based is the positive Y-axis. A line perpendicular to this meridian through an assumed origin is the X-axis. Note that the X-axis is positive in an easterly direction. Give an example, showing the coordinates of several points.
C. Positive quantities	Tell the class that usually the coordinates of all the points in the survey are made positive quantities. This is done by placing the origin far enough south and west.
D. Computations	State that before the coordinates of the points in a traverse can be computed, the coordinates of at least one point in the traverse must be known. (Ref. A, pp. 463-468) Show that the coordinates of station B are computed when the coordinates of station A are known in the line AB. 1. The Y coordinate of station B is determined by adding (or subtracting) the latitude of line AB to the Y coordinate of station A. 2. The X coordinate of station B is determined by adding (or subtracting) the departure of line AB to the X coordinate of station A. Point out that the bearings and distances of the lines can be computed by the simple trigonometric functions of right triangles. This can be done if the coordinates of the points are known.
IV. New York State Coordinate System	Mention that the methods of plane surveying are based on the assumption that all distances and directions are projected onto a horizontal plane surface. This surface is tangent to the surface of the earth at one point

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	within the area of the survey. State coordinate systems provide one set of plane rectangular coordinates to serve the whole area of a small state or a portion of the area of a large state. (Ref. A, pp. 415-417; Ref. B, pp. 340-341)
A. Limits of a system	Explain that in two independent surveys the measurements in each survey are referred to two different horizontal planes which do not coincide. (Ref. B, pp. 342-345)
	Point out the effect of convergency of the meridian. If the Y-axis of a plane coordinate system for each of the two surveys is assumed to be parallel to the true meridian, then even the Y-axes of the two systems are not parallel with one another.
	State that in any system the farther away measurements are made from the point of tangency, the more will the distances and angles as measured on the ground differ from the corresponding distances and angles projected on a horizontal plane. When this condition becomes intolerable, the limits of plane surveying have been reached.
B. Geodetic surveying	Advise the class that the methods used in precise geodetic surveying are designed for the spheroidal surface of the earth. Angles in triangles are considered to be spherical. Coordinates of points are computed with references to parallels of latitude and meridians of longitude. This is done by using angles computed near the center of the earth rather than distances.
	Add that geodetic surveying does not have the limitations of plane surveying and that precise work may be done over large areas of land. Precise work of this type is more complex and more expensive.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	Mention that much of this work is covered in Unit II of this series, "Highway Drawing."
C. United States Coast and Geodetic Survey	Mention that for a century the U.S. Coast and Geodetic survey has been establishing horizontal *control monuments*. These take the form of triangulation, traverse, and intersection stations, and are placed only after precise geodetic surveying. Note that all the control points in the country bear a definite relationship to each other--all refer to one common *spheroidal* surface. (Ref. B, p. 341)
D. State systems	Explain that state coordinate systems have been devised to allow methods of plane surveying to be used over a great distance in any direction. This enables precision to be maintained equal to that of geodetic surveying.
1. Highway control	Point out that precision is of great importance in highway surveying because a highway often covers a long distance. With the coordinate system, each end of the highway can be tied, forming a closed traverse.
E. Application of a state coordinate system	Explain that because of the transformation from the spheroidal surface of the earth to one horizontal plane, there are varying applications to a state system: 1. If the state is small, it can be embraced in one projection. 2. If the state is large, it can be divided into zones broken along county lines.
1. Types of projections	
a. Transverse Mercator	Describe the *transverse Mercator projection* as employing a cylindrical surface. The axis is normal to the earth's axis of rotation and intersects

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

the surface of the earth along two ellipses. These ellipses are equidistant from a meridian plane through the center of the area to be projected (Ref. B, pp. 346-349):

1. This causes distortions in an east-west direction. It is thus used for states or zones having short east-west dimensions, such as Vermont.

2. New York State adopted its coordinate system on July 1, 1939. The State was divided into four zones, three of which are transverse Mercator projections.

3. The East, Central, and West zones have central meridians of 74°20' W., 76°35' W., and 78°35' W., respectively. The origin of coordinates is at the intersection of each of these meridians with the parallel 40°00' N.

4. Each of these origins is given by x = 500,000 ft. and y = 0 ft.

b. Lambert conformal

Describe the *Lambert conformal projection* which employs a conical surface. Its axis coincides with the earth's axis of rotation and intersects the surface of the earth along two parallels of latitude. These parallels are approximately equidistant from a parallel lying in the center of the area to be projected. (Ref. B, pp. 357-360):

1. This causes distortion in a north-south direction. It is thus used for states or zones having short north-south dimensions like Tennessee.

2. The fourth zone of New York State (Long Island) is a Lambert conformal projection.

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

3. The origin of coordinates is at the intersection of the meridian 74°00' W. and the parallel 40°30' N. at x = 2,000,000 ft. and y = 100,000 ft.

2. Actual error

Mention that if the east-west distances in the transverse Mercator projection and the north-south distances in the Lambert projection are limited to 158 miles, the distortions would not be greater than 1/10,000.

3. Geodetic and grid azimuths

Tell the class that when a survey is placed on a system of plane rectangular coordinates, all bearing and azimuths are referred to the same meridian. Characteristics of the survey are (Ref. B, p. 345).

1. The system is rectangular. All grid north and south lines are parallel to the central meridian.

2. The convergence of meridians causes a difference in the grid bearing and geodetic bearing of a line. The difference increases with the latitude and the distance away from the central meridian.

3. The difference between the grid azimuth and the geodetic azimuth of a line is indicated by the symbol θ (theta) on the Lambert grid. On the transverse Mercator grid the difference is indicated by the symbol $\Delta\alpha$ (delta alpha).

F. Advantages of a state coordinate system

List the following advantages in using the State Coordinate System (Ref. B, pp. 372-373):

1. Standardizes and unifies surveys

2. Increases the permanency of surveys

3. Provides more accurate results

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	4. Reduces cost of survey work
	5. Insures better records
	6. Prevents mistakes
	7. Allows lost points to be replaced
	8. Conforms maps of the same location
	9. Provides less expensive photogrammetric mapping
V. Stadia Surveying	Define the term *stadia surveying* as the method of obtaining horizontal distances and differences in elevation. This is accomplished with the optical geometry of the lens, the crosshairs of the telescope, and the transit reading of the vertical circle. (Ref. A, pp. 350-358; Ref. B, p. 413)
A. Procedure	Explain that this is a process by which the angle at the instrument is measured by observing two points on a *graduated rod.*
	Note that stadia surveying is used when low accuracy is permitted.
B. Principle of transit stadia measurements	Point out that the transit telescope is equipped with three horizontal crosshairs; the upper and lower hairs are called the stadia hairs. (Ref. A, pp. 354-357)
	Draw a sketch on the chalkboard, showing the telescope, the lens, the focal point, and the rod.
1. Space between the stadia crosshairs	Call the distance between the upper and the lower hairs i.
2. Laws of optics	Discuss the laws of optics. Explain that a ray of light parallel to the optical axis of a lens will pass through the principal focus of the lens on the opposite side. (Ref. A, pp. 354-355; Ref. B, pp. 413-416)

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
3. Focal length	Show this point on the sketch as point F. Show the distance from the center of the lens to F as the focal length of the lens, *f*. This is constant for a given lens. Explain that a ray of light will be bent at the bottom of the lens, pass through F, and strike the rod at a point B, above the optical axis. Similarly a ray of light will be bent at the top of the lens, pass through F, and strike the rod at a point A, below the optical axis.
4. Stadia interval	Mention that this distance AB on the rod is called *s* or *stadia interval*. It is found by subtracting the stadia hair reading at A from the stadia hair reading at B. Find by similar triangles that the distance R (from F to the rod) is equal to the focal length (f), over the stadia hair spacing (i), times the stadia interval: $$R = \frac{fs}{i}$$
5. Stadia interval factor	State that the ratio f/i is called the stadia interval factor, or K, which defines R as Ks. Note that the manufacturers of most instruments space the stadia hairs so that K is equal to 100.
6. Total horizontal distance	Show on the sketch how the total horizontal distance *D*, from the centerline of the telescope to the rod is derived. This consists of R (from focal point to rod), plus f (the focal length from focal point to lens), plus c (from lens to centerline of instrument).
7. Stadia equation for a horizontal line of sight	Add that c is variable and negligible so that the term f + c is called stadia constant C. This defines the total distance D as equal to R + C or Ks + C.

CONTENT OUTLINE		TEACHING POINTS AND TECHNIQUES
		State that the stadia constant C is printed on the box which houses the transit. It varies from 0.6 to 1.4 but in the new type of internal focusing telescope it is always equal to 1.00.
		Conclude that since D = Ks + C, the stadia interval read on the rod is multiplied by 100. Then the constant is added for a horizontal distance.
		Emphasize that this is applicable only when the line of sight is inclined less than 3°.
VI.	Inclined Line of Sight	Advise the class that the *inclined* measurements are more frequent than the horizontal ones. (Ref. A, pp. 356-358; Ref. B, pp. 416-419)
	A. Geometry of line of sight	Show by sketch that the inclined stadia measurement must be reduced geometrically to find the horizontal distance, H.
		Describe briefly the geometry of this conversion. Also describe the difference in elevation between the center of the telescope and the middle cross-hair reading, V.
	B. The vertical angle	Stress that the inclined angle is measured on the *vertical circle* of the transit.
	C. Tables	Explain that the computations for each inclined sight are a tedious task and tables are used to facilitate the work. (Ref. A, Table 9; pp. 959-966; Ref. B, Table A, pp. 643-650)
	1. Use of tables	Set up an example for the class and demonstrate the use of the stadia tables.
VII.	Difference in Elevation Between Two Points	Explain to the class the significance of the vertical distance, V, found in the tables or by computation. This value comprises the distance from the centerline of the telescope to the

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	middle crosshair reading. This is not the true difference in elevation between the ground level at the transit and the ground level at the rod. (Ref. A, pp. 363-365; Ref. B, pp. 420-422)
A. Total difference in elevation	Identify the elements that make up the total difference in elevation. The difference is the distance from the centerline of the telescope to the ground, or H.I., plus the vertical distance, V, minus the middle rod reading (distance from reading on rod to the ground under the rod). Stress to the class that this difference in elevation is the H.I. minus V, minus rod reading, if the vertical angle is negative.
B. Rapid procedure	Explain that if the middle crosshair is set on the rod at the H.I. elevation, then the vertical distance, V, is the difference in elevation.

QUESTIONS FOR REVIEW

1. What is the sum of all of the *interior angles* of a closed traverse?
2. Explain what is meant by a *field execution* of a traverse.
3. What is the *projection of a line* on the meridian?
4. How is the *projection of a line* on the meridian found?
5. What is the mathematical summation of *latitudes* and *departures*?
6. Describe the *linear error of closure*.
7. Define *closure precision*.
8. What is the *compass rule* as used to balance a survey?
9. What is the *transit rule* as used to balance a survey?
10. Compare the *compass rule* with the *transit rule*.
11. How is it possible to avoid the use of a *negative coordinate* when establishing a *plane coordinate system*?

12. Explain how the *United States Coast and Geodetic Survey* system, utilizing one common spheroidal surface, can be reconciled with the *State Coordinate System.*

13. What is the maximum distance in miles which limits the distortion to less than 1/10,000 in the State Coordinate System?

14. Name six advantages of a *state coordinate system.*

15. Describe what is meant by *stadia interval.*

16. What is the *stadia constant* of an *internal focusing* telescope?

17. How can the true difference in elevation be determined when using stadia?

ASSIGNMENT

1. Solve problems 1-4, 7, and 8 on pages 375-376 of Ref. A.

2. Solve problems 1, 2, 4, 8, and 11 on pages 474-476 of Ref. A.

3. Study Chapter 20, pages 502-527 of Ref. A.

4. Study Chapter 21, pages 529-546 of Ref. A.

Lesson 11

PRINCIPLES OF FIELD ASTRONOMY

OBJECTIVES

1. To provide the student with the fundamentals of field astronomy
2. To teach the students how to locate the true bearing or azimuth of a line

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. Introduction to Field Astronomy	State that a knowledge of practical *astronomy* is necessary for determining latitude, time, longitude, and azimuth. (Ref. A, pp. 502-521; Ref. B, p. 375)
A. Application	Tell the class that astronomy is used to determine the absolute location of a point and the absolute direction of a line. Absolute location is the latitude and longitude. Absolute direction is true north or true meridian.
B. Scope	Mention that a complete coverage of field astronomy is beyond the scope of this course. But the information presented here will enable the student to perform certain field operations. These include the securing of the correct standard time and a true azimuth from *solar* observations. Explain that time, latitude, longitude, and true azimuth may also be determined from observations of certain stars.
C. Relationship of stars to earth	Point out that the various heavenly bodies are assumed to be located on the surface of a sphere of infinite radius. The center of the earth is the center of the celestial sphere.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
D. Definitions of terms	Draw a sketch of the celestial sphere on the chalkboard. Place the earth at its center. (Ref. B, pp. 376-380) Describe the terms that apply to field astronomy:
1. Celestial poles	The two points of contact made on the celestial sphere when the line of the earth's axis of rotation is extended in both directions.
2. Celestial equator	The intersection of the celestial sphere with a plane passing through the center of the earth, perpendicular to the axis of rotation.
3. Zenith	The extension of a vertical line at any point on the surface of the earth. It intersects the upper portion of the celestial sphere at the zenith and the lower portion of the celestial sphere at the nadir.
4. Vertical circle	A great circle (with full diameter of the celestial sphere) passing through the zenith and the nadir.
5. Meridian plane	A plane passing through the celestial poles.
6. Meridian	One of the intersections of a meridian plane with the celestial sphere. (Degrees of longitude are measured east and west of Greenwich.)
7. Hour circle	A great circle passing through the north and south celestial poles.
8. Horizon	The intersection of the celestial sphere with a plane that passes through the center of the earth, perpendicular to a vertical line.
9. Azimuth (of a heavenly body)	The angular distance measured along the horizon from the south point of the meridian to the vertical circle through the heavenly body. The azimuth is positive when measured clockwise.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
10. Altitude (of a heavenly body)	The angular distance measured upward from the horizon along a vertical circle. The *co-altitude* or *zenith distance* is equal to 90° minus the altitude.
11. Latitude	The angular distance measured along the meridian from the equator toward the zenith of a given point. Latitudes north of the equator are considered positive. Those south of the equator are negative. The symbol for latitude is the Greek letter phi (ϕ).
12. Declination	The angular distance measured from the equator to a body along the hour circle through the body. If the body is north of the equator, the *declination* is positive. If it is south, the declination is negative. The symbol for declination is the Greek small letter delta (δ).
13. Transit	The transit of a heavenly body is its path over the observer's meridian.
14. Refraction	The angular increase in *apparent* altitude due to the refraction of light. *Refraction correction* is always negative and is a maximum when the altitude is small.
15. Correction for parallax	A small angular increase in the apparent altitude of a heavenly body to allow for the fact that the observations are made at the surface of the earth instead of at its center.
16. Ephemeris	The annual report of the behavior of the sun and the more important stars used in field astronomy. Pass out copies of the *ephemeris* and discuss some items found in the booklet: 1. Information about the parts of surveying instruments 2. Use of the instruments

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	3. Miscellaneous data
	4. Trigonometric functions
	5. Concept of celestial observations
	6. Daily calendar for the current year, listing the sun's apparent declination for each day with the difference in declination for one hour
	7. The question of time for each day
	8. Tables of refraction and parallax
	9. Tables for the sun's semidiameter
a. Source of ephemeris	
(1) Publications	Advise the class that several companies which make survey equipment publish an ephemeris. These are generally given as an advertisement.
b. Cost	Mention that the official ephemeris published by the U.S. Department of the Interior sells for about 30 cents.
c. Time	Inform the class that there are two kinds of time involved in solar observations. (Ref. A, pp. 521-527; Ref. B, pp. 380-383)
(1) True solar time	Describe a *true solar day* (apparent solar day) as the interval of time between two successive lower transits of the sun's center over a given meridian.
	Point out that successive lower transits vary day to day. There are two reasons for this -- 1. The plane of the earth's orbit is oblique. 2. The earth's angular velocity about the sun in its elliptical orbit varies. If we kept time in accordance with this, it would be very confusing.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
(2) Mean solar time	Stress that *mean solar time* overcomes the erratic pattern of true or apparent solar time. This is true because it is the interval of time between two successive lower transits of the mean sun over the same meridian. Tell the class that mean solar time is based on a fictitious sun which travels at a uniform rate along the equator. Sometimes it leads the true or apparent sun, sometimes it lags. State that mean solar time at any instant for a given meridian is the hour angle of the mean sun, referred to the same meridian, plus 12 hours. At midnight the hour angle of the mean sun is 12 hours. At mean solar noon the hour angle of the mean sun is zero hour.
(3) Equation of time	Describe the equation of time as the difference between apparent solar time and mean solar time. Its value for each day of the year is listed in the ephemeris. (Ref. A, p. 523)
(4) Standard time	Emphasize that standard time is the mean standard time referred to in meridians, 15° apart. This is measured from Greenwich, which is at zero degrees longitude. (Ref. A, p. 527; Ref. B, p. 381) Show that the meridians are 1 hour apart in time. Eastern standard time is the time of the 75th meridian west of Greenwich. Point out that the standard time referred to the Greenwich meridian is called *Greenwich civil time* (GCT), or *universal time*.
(5) Local time	Define local time as that based on the observer's meridian. (Ref. B, p. 382) Show that *local civil time* (LCT) is based on mean solar time. It is the hour angle of the mean sun measured from the local meridian, plus 12 hours.

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

Remind the class that *local apparent time* (LAT) is based on the true (apparent) sun and is the hour angle of this sun plus 12 hours.

Point out that when the sun's actual center is on the observer's meridian, it is local apparent noon.

Give some examples in time. At a certain instant the time is 10:42 a.m., Pacific standard time, and the place is at longitude 121°33'20" where standard time is based on the 120th meridian. (Ref. A, pp. 525-527):

1. Local civil time is earlier by an amount equal to 1°33'20" or $6^m\ 13.3^s$. (m = minutes of time, and s = seconds of time.)

2. Conversions from degrees, minutes, and seconds to hours, minutes, and seconds is based on:

   $360° = 24^h$ $\quad 1' = 4^s$
   $1° = 4^m$ $\quad 1'' = 0.067^s$

3. Local civil time at longitude 121°33'20" is 10:35:46.7 a.m.

Give other examples of time analysis.

II. Solar Observation

Explain that the purpose of solar observation is to obtain information about the position of the sun in altitude and azimuth (referred to a line on earth). This data is required so the true azimuth of the line on earth may be determined.

A. Observations on the sun

Mention that the altitude of the sun is measured on the vertical circle of the transit and that the azimuth is measured on the horizontal circle. (Ref. A, pp. 530-546; Ref. B, pp. 383-389)

1. Difficulties

Note the difficulty in setting the crosshairs directly on the center of

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	the sun (unless a special reticule is available). The crosshairs are made tangent to the edges of the sun, with the necessary correction added or subtracted to achieve a reading to the center of the sun.
2. Standard practice	State that in the morning hours the sun is rising, so the lower edge or limb is observed for altitude. During the afternoon hours the altitude of the sun is decreasing, so the upper limb is observed. Throughout the day the sun is moving from east to west and the east limb is observed for azimuth. Stress that all three observations are made on the trailing limb.
B. Procedure	Describe the procedure for observing the sun: 1. Set up and level the transit and point the telescope in the horizontal direction of the sun. (Ref. A, p. 532; Ref. B, pp. 385-389) 2. Center the telescope bubble and check the vertical circle for any index error. 3. Raise the telescope and point it at the sun without actually looking through the telescope. (Eyes may be damaged unless the telescope is equipped with a prismatic eyepiece or special solar attachments.) 4. Hold a white card about 3 or 4 in. behind the eyepiece and move the telescope in altitude and azimuth until a circular shadow is cast on the card. 5. Focus the crosshairs until they are visible on the card. Then focus the telescope to make the image of the sun clear and sharp on the card.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
1. Error caution	Remind the class that the image of an erecting telescope will be upside down on the card. The lower edge of the sun's image is actually the upper limb of the sun. The left edge of the sun's image is the eastern limb of the actual sun.
C. Tangency of the crosshairs	Make some sketches for the morning and afternoon sun and show how the crosshairs are brought tangent to the proper limbs of the sun. (Ref. B, p. 388)
1. Diameter in minutes	Mention that the diameter of the sun is 32' and its semidiameter (about) 16') is listed for different times of the year in the ephemeris.
2. Correction	Point out that the vertical angle is corrected for index error, parallax, and refraction before the semidiameter is added (morning) or subtracted (afternoon).
	Note the condition when the vertical crosshair is placed tangent to the eastern limb. The horizontal circle reads too small by an amount equal to the semidiameter times the secant of h, the altitude or vertical angle.
	Give some examples, using definite days so that exact corrections may be found in the ephemeris.
D. Multiple readings needed	Explain that several observations should be taken in rapid succession to obtain multiple readings. The values of the vertical and horizontal angles and the time of each shot are recorded. (Ref. B, p. 388)
	Stress the fact that the *watch time* should be noted to the nearest second whether the watch is correct or not.
	Show that the horizontal and vertical angles are plotted on left and right coordinates in a graph, against the time on the abscissa. A mean value is taken from this graph.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
III. Latitude and Longitude	Emphasize that both the latitude and longitude can be scaled quite accurately from a large scale topographical map. The latitude can be computed from determining the difference in time between the unknown point and some point of known longitude. (Use, for example, radio time signals from the Naval Observatory at Washington, D.C.) (Ref. A, pp. 537-539; Ref. B. p. 395)
IV. Determination of Standard Time	Caution the class that although the prime purpose of astronomical observations is the determination of the true azimuth of a line, it may be necessary to know the standard time within one or two seconds. (Ref. A, pp. 542-545)
A. By transit of the sun	State that the exact time may be determined by noting the instant the sun's center passes the meridian. (Ref. A, p. 542; Ref. B, p. 390)
B. By altitude of the sun	Add that the time may also be determined from the altitude of the sun at any instant. (Ref. B, p. 391)
1. Watch error	Point out that this determination of time will measure the amount of error in watch time.
	Remind the class that the center of the sun cannot be located. Therefore a reading is made on the lower limb in the morning, and upper limb in the afternoon. The observed angle is corrected for *index error*, *refraction*, *parallax*, and *semi-diameter* of the sun.
2. Hour angle	State that the following formula is used for determining the hour angle, which can be converted:
a. Formula	$\cos t = \frac{\sin h - \sin \phi \sin \delta}{\cos \phi \cos \delta}$
b. Terms	Give the meaning of each letter:
	1. The hour angle is t.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	2. The latitude is ϕ.
	3. The declination obtained from the ephemeris is δ.
	4. The corrected altitude is h.
	5. The polar distance, or 90° - δ, is p.
c. Cautions	Note that the approximate time must be known so the declination may be obtained from the ephemeris. If the time used or estimated varies too far from the correct time, the operation must be done again.
	Advise the class that the best results are obtained when the observed altitude is about 20° and the time is one hour before noon or one hour after noon.
d. Class problem	Work out a problem on the chalkboard and have the students find the required information from their copies of the ephemeris. Use logarithms unless a desk computer is available.
V. Solar Observations for Azimuth	Indicate that the azimuth of a line may be determined whenever the time is known to within one or two minutes. This is done by measuring the horizontal angle from the line to the sun's center and then measuring the altitude of the sun's center. (Ref. A, pp. 539-542; Ref. B, pp. 401-409)
A. Mean values	Impress upon the class that eight measurements are taken, four with the telescope direct and four with it reversed, all in quick succession. This will give results reliable to 15", using a 30" transit.
B. Procedure for solar observations	Describe the procedure for making solar observations for azimuth:
	1. Set up and level the transit over point A. Level the telescope, and record any index error on the

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

vertical circle. Set horizontal circle to read 0°00'00", and take a backsight on point B. (Draw a sketch on the chalkboard, showing the pattern of this procedure.)

2. Loosen upper clamp and point the telescope at the sun, obtaining an image on a white card.

3. Take four observations in this manner, recording the horizontal angle, the vertical angle, and the time at the instant of tangency.

4. Reverse the telescope and repeat the procedure described above.

5. Loosen upper clamp and backsight to transit point B, checking out with 180°00'00" on the horizontal circle.

6. Correct the horizontal and vertical angles and plot against time for mean values.

7. Reject any readings which are obviously wrong.

C. Formula for azimuth

Tell the class that there are several formulas. The following formula will be used in this class to determine the azimuth of the sun:

$$\tan \tfrac{1}{2}Z = \sqrt{\frac{\sin (s-\phi) \sin (s-h)}{\cos s \cos (s-p)}}$$

Give the meaning of each letter:

1. The azimuth of the sun, measured from the north, is Z.

2. The latitude is ϕ.

3. The corrected altitude is h.

4. The declination taken from ephemeris is δ.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	5. The quantity $\frac{1}{2}(\phi + h + p)$ is s.
	6. The polar distance, or $90° - \delta$, is p.
D. Observations	Note that the best results are obtained when the observations are made between 8:00 a.m. and 10:00 a.m. or between 2:00 p.m. and 4:00 p.m.
	Stress that the solution of the equation furnishes Z, the azimuth of the sun from true north.
	Show by sketch how the true azimuth of the line AB is found.
E. Problem	Distribute a completely worked-out problem on any standard working form. Follow through the steps of the problem with the students. (Ref. A, p. 540; Ref. B, p. 406)

QUESTIONS FOR REVIEW

1. What are the *celestial poles*?
2. What point is exactly opposite the *zenith*?
3. Describe the *azimuth* of a heavenly body (star or sun).
4. Explain what *declination* is.
5. Why does *refraction* affect a transit reading?
6. Why does the phenomenon of *parallax* require a correction?
7. Describe a *true solar day*.
8. What is the *equation of time*?
9. What is the difference between *standard time* and *local time*?
10. Why is the lower edge of the sun's *image* actually the upper limb of the sun when using the transit in a solar observation?
11. How is the time determined from the altitude of the sun at any instant?
12. If the horizontal angle from a base line to the center of the sun is measured, and if the altitude of the center of the sun is known, what can be computed at a given time?

ASSIGNMENT

1. Solve problems 1-8 on page 528 of Ref. A.

2. Solve problems 2-4, 6, 9, 15, and 17 on pages 567 and 568 of Ref. A.

3. Study Chapter 27, pages 714-726 of Ref. A.

Lesson 12

HORIZONTAL CURVATURE

OBJECTIVES

1. To familiarize the student with the geometry of horizontal curvature and its use in highway alignment
2. To describe the compound curve, the reverse curve, and the spiral curve

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. Horizontal Alignment	Define *horizontal alignment* as a line which consists of straight lines connected by curves. (Ref. A, pp. 714-715; Ref. B, pp. 269-270)
A. Change of direction	Point out that if a highway were constructed from terminal A to terminal B, it is improbable that these points could be connected with a straight line. Tell the students that because of many conditions (deep swamps, mountains, bodies of water, housing developments), it becomes necessary to change direction for highway design.
B. Tangents	Indicate that sections of straight lines are tangent to the change of direction or curves.
C. Point of tangency	Note that at a designated point on the tangent an abrupt change occurs from moving in a straight line to moving in a circle.
D. Curves	State that there are many ways to achieve a change in direction from the tangent. The most widely used method involves the use of a simple circular curve.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	Draw a sketch on the chalkboard, showing two tangents connected with a simple curve. Use colored chalk on all sketches.
II. Nomenclature	Advise the class that in introducing the simple curve many new expressions will be used but no new geometry will be encountered. Emphasize that the *stationing* of a route progresses around a curve in the same manner that it does on the tangents. As shown on all plans, the stationing will increase from left to right.
A. Point of curvature	Make an appropriate sketch on the chalkboard, mark the point where the circular curve begins and call it the *point of curvature*, or P.C.
B. Point of tangency	Call the point where the curve ends the *point of tangency*, or P.T.
C. Point of intersection	Identify the point of intersection (P.I.) of the two tangents as the *vertex* of the tangents.
D. Tangent distance	Point out that the distance along the tangent from P.C. to P.I. is the *tangent distance*, T. This is equal to the distance along the tangent from P.I. to P.T.
E. Center of curvature	Draw radii perpendicular to the tangents at P.C. and P.T. which will intersect at point O (the center of curvature).
F. Radius	Mark the radii of the curve, R. These are at right angles to the tangents at the ends of the curve.
G. Length of curve	Show the distance along the curve as L (the *length of curve*). This is measured along the curve from P.C. to P.T.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
H. Long chord	Draw a straight line from P.C. to P.T. Call this the *long chord*, C.
I. External distance	Connect the vertex (P.I.) to the radii at O (the *center of curvature*). Call the distance from P.I. to the curve, measured along this radial line, the *external distance*, or E.
J. Middle ordinate	Call the distance from the long chord, C, to the middle of the curve, measured along this same radial line, the *middle ordinate*, or M.
K. Deflection angle	Name the *deflection angle* between the tangents, the *intersection angle*, Δ (delta). This is equal to the angle between the radii at the point of curvature, O.
III. Degree of Curve	Describe the *degree of curve* as the angle at the center subtended by an arc 100 ft. long. This is called *D*. (Ref. A, p. 715; Ref. B, p. 271)
A. Sharpness of curve	Explain that sharpness can be expressed either by the degree of curvature or by the length of radius--the sharper the curve, the shorter the radius.
B. Radius of 1° curve	Compute the length of radius of a 1° curve. See Figure 1.

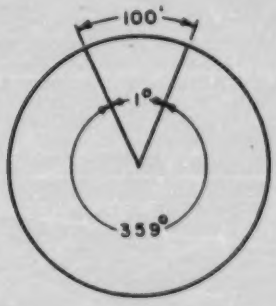


Figure 1
RADIUS OF A 1° CURVE

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

Repeat that by definition the angle at the center is 1° when the subtended arc is 100 ft. By proportion:

$$\frac{1^\circ}{360^\circ} = \frac{100'}{2\pi R} = \frac{100}{\text{Circumference}}$$

Solving for R:

$$R = \frac{(100')\ (360^\circ)}{1^\circ\ (2\pi)} = 5729.58'$$

State that 5730 ft. is used as the length of radius for a 1° curve.

C. Relationship between the deflection angle and the degree of curvature

Inform the class that the tangent distance indicates the relationship between Δ and D. Use Figure 2 to show this relationship and leave the figure on the chalkboard for future reference in derivations. (Ref. A, pp. 716-718)

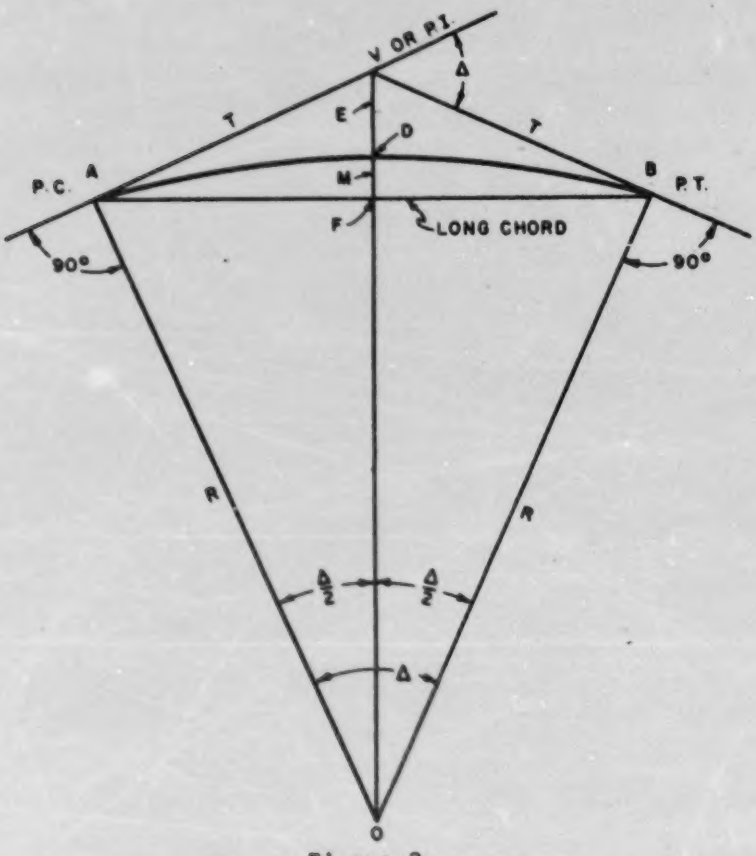


Figure 2
DERIVATION OF ELEMENTS OF THE SIMPLE CURVE

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

1. Derivation

Derive the equation for the *tangent distance*:

$$T = R \tan \frac{\Delta}{2}$$

2. Relationship of Δ, D, and T

Sketch Figure 3 on the chalkboard and show the relationship between the deflection angle, the degree of curvature, and the tangent distance.

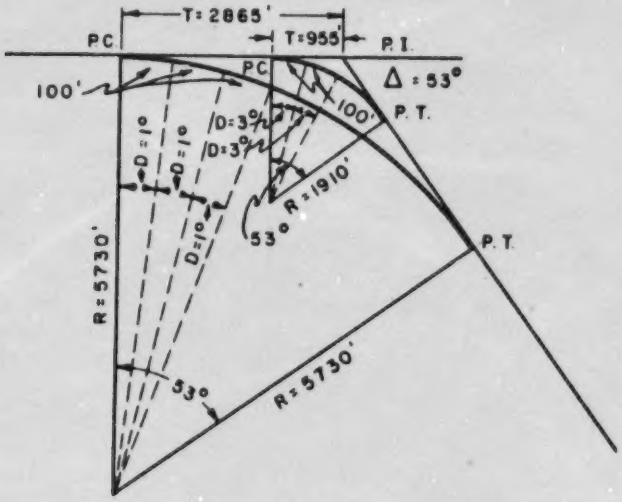


Figure 3
RELATIONSHIP OF Δ, D, AND T

3. Computations for T

Compute the tangent distance for 1° and 3° curves, using a deflection angle of 53°.

Solution for $\Delta = 53°$, $D = 1°$, $R = 5730'$

$$T = R \tan \frac{\Delta}{2} = 5730 \times \tan \frac{53}{2}$$
$$= 5730 \times 0.5 = 2865'$$

Solution for $\Delta = 53$, $D = 3°$, $R = 1910'$

$$T = R \tan \frac{\Delta}{2} = 1910 \times 0.5 = 955'$$

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

4. Computations for L

Indicate that when D = 1°, 1° of the central angle subtends an arc of 100 ft. Therefore, 53° of the central angle will subtend an arc of 5300 ft., which equals L.

Add that when D = 3°, 3° of the central angle will subtend an arc of 100 ft., so 53° of central angle will subtend an arc of

$$\frac{53}{3} \times 100 = 1767' = L$$

Point out that in this formula

$$L = \frac{100\Delta}{D}$$ or by geometry:

$$\frac{53^\circ}{360^\circ} = \frac{L}{2\pi R}$$ and $L = 5300'$

Note that the delta angle is always converted into decimals of a degree, from minutes and seconds.

IV. Formulas

Derive the equation for the external distance from triangle AOV in Figure 2:

$$\cos\frac{\Delta}{2} = \frac{R}{R+E};\quad R + E = \frac{R}{\cos\frac{\Delta}{2}};$$

$$E = \frac{R}{\cos\frac{\Delta}{2}} - R.$$

Derive the equation for the middle ordinate distance. From triangle AOF:

$$OF = R\cos\frac{\Delta}{2};\quad OF + FD = R;$$

$$FD = R - OF = R - R\cos\frac{\Delta}{2} = M.$$

Derive the equation for the long chord:

$$\text{Sin}\frac{\Delta}{2} = \frac{AF}{R};\quad AF = \tfrac{1}{2}\,AB$$

AB is the long chord.

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

$$AF = R \sin \frac{\Delta}{2}$$

$$2AF = 2R \sin \frac{\Delta}{2} = C$$

A. Problem

Explain that the usual information that is available is the location of the tangents and the deflection angle of the tangents. These are constant, but the degree of curve to be used is variable and will depend on standards.

State that the most common error made in computing curve data is in the stationing of the curve; the stationing to the P.I. is known (distance along the tangent). Show that the stationing must *backtrack* from the P.I. to the P.C., and then proceed around the curve.

Set up a problem on the chalkboard and find the stations of the P.C. and P.T., the external distance, the middle ordinate, and the long chord. Given: At station 30 + 00 of a centerline, it is decided to change direction by 53°, using a 3° curve.

Make a sketch and show each element as it is computed:

$$\Delta = 53°;\ D = 3°;\ R = \frac{5730}{3} = 1910'$$

$$T = R \tan \frac{\Delta}{2} = (1910)(0.5) = 955'$$

$$L = \frac{100\Delta}{D} = \frac{(100)(53)}{3} = 1767'$$

P.I. is at station	30+00
Tangent distance	- 9+55
P.C.	20+45
L	+17+67
P.T.	38+12

$$M = R - R \cos \frac{\Delta}{2} = 1910 - 1910 \times 0.895$$

$$M = 1910 - 1710 = 200'$$

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

$$E = \frac{R}{\cos \frac{\Delta}{2}} - R = \frac{1910}{.895} - R =$$

$$2135 - 1910 = 225'$$

$$C = 2R \sin \frac{\Delta}{2}$$

$$2 \times 1910 \times 0.446 = 1710'$$

V. Field Layout

State that when the curve data is complete, the curve must be located in the field.

Point out that the most convenient method of locating points on a circular curve is by means of *deflection angles* from the tangent.

A. Procedure

Describe the procedure for locating points on a circular curve in the field:

1. Set up and level the transit at the P.I.
2. Use the transit to sight along the tangents, measuring the tangent distance off on both the *back tangent* and the *forward tangent*. (Ref. A, pp. 718-721; pp. 274-276)
3. Bisect the interior angle at the P.I. and set in the midpoint of the curve. This is done by measuring off the external distance from the P.I. to the curve along the bisector of the interior angle.
4. Move the transit to the P.C. of the curve. Locate the points on the curve by turning off the computed deflection angles from the tangent.

B. Computation of deflection angles

Refer to Figure 2 and set the delta angle equal to 30° for computation of deflection angles. (Ref. B, pp. 273-274)

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
1. Derivation	Consider the triangle ABV, formed by the long chord from P.C. to P.T., the tangent from P.C. to P.I. and the tangent from P.I. to P.T. Establish that if the delta angle is 30°, the angle at V, the interior angle between the tangents, must be 150°. Add that if the angle at V is 150°, the angles at A and at B must equal 30°. Since the angle at A equals the angle at B, they must each be 15°.
2. Concept	Assume that the transit is set up at point 0, the center of curvature. The total deflection from P.C. to P.T. would be 30°. Reiterate that when the transit is at the P.C., the total deflection to P.T. is 15°, that is, angle A. Conclude that any deflection with the transit at P.C. is one-half of what the deflection would be to the same point if the transit were at point 0. Assume that the transit is at point 0, sighted at the P.C., and an angle equal to D is turned. An arc of 100 ft. would be subtended along the curve. If the transit is at the P.C., an angle of only ½D would be turned to subtend an arc of 100 ft. Stipulate that to establish points every 100 ft. on the curve, the transit is set up at the P.C. and *deflections* of ½D are turned. The first deflection of ½D is for the first 100 ft., then ½D plus ½D is added for the second 100 ft., etc. For each succeeding 100 ft. add ½D to the previous angle.
3. The P.C.	State that in most cases the P.C. will not be at a full station. If this condition exists it may be necessary to compute the deflection to the first even station instead of a full 100 ft.

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

Outline a *direct proportion* method of computation: e.g., if the P.C. is at station 12 + 60, the first deflection is made to station 13 + 00, or for a distance of 40 ft. Use 40/100 of the full deflection, which is ½D.

Offer another method--the computation of the *odd deflection* in minutes. Use the formula 0.3 cD, where c is the subchord, or 40 ft., and D is the degree of curvature.

Note that in most cases the curve is staked out in 50-ft. intervals. For this interval the deflection is ½D.

C. Computing deflection

Proceed to show the class a typical problem. Set up the deflections for a 400-ft. curve when delta is 8°, D is 2°, the P.C. is at station 44, and the P.T. is at station 48:

1. Set the transit at the P.C., and sight at the P.I.
2. The first deflection is to station 45 and is equal to D/2 or 1°.
3. The second deflection is to station 46 and is equal to D/2 plus D/2 or 2°.
4. The third deflection is to station 47 and is equal to D/2 plus D/2 plus D/2 or 3°.
5. The fourth deflection is to station 48, the P.T., and is equal to D/2 plus D/2 plus D/2 plus D/2 or 4°.

Show that the last deflection to station 48, the P.T., is ½ of the delta angle, or 8/2 or 4°. This step is a check on the work.

Give the class another exercise. Tell them to find the deflections to stake out the curve every 50 ft. Given:

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

$\Delta = 54°20'$; $D = 7°40'$

$L = 708.70$

P.C. is at station 121 + 56.35

P.T. is at station 128 + 65.05

Sub-chords--122 + 00.00 - 121 + 56.35 = 43.65

0.3 c D (0.3)(43.65)(7.67) = 100.4' = 1°40.4'

128 + 65.05 - 128 + 50.00 = 15.05"

0.3 c D = (0.3)(15.05)(7.67) = 34.6'

D/2 = 3°50' and D/4 = 1°55'

P.C. station 121 + 56.35
122 + 00.00 = 1°40.4'
122 + 50.00 = 3°35.4'
123 + 00.00 = 5°30.4'
123 + 50.00 = 7°25.4'
124 + 00.00 = 9°20.4'
124 + 50.00 = 11°15.4'
125 + 00.00 = 13°10.4'
125 + 50.00 = 15°05.4'
126 + 00.00 = 17°00.4'
126 + 50.00 = 18°55.4'
127 + 00.00 = 20°50.4'
127 + 50.00 = 22°45.4'
128 + 00.00 = 24°40.4'
128 + 50.00 = 26°35.4'
128 + 65.05 = 27°10'

Check deflection to P.T. at station 128 + 65.05 or (0.3)(708.70)(7.67) = 1630' = 27°10'

or $\frac{\Delta}{2} = \frac{54°20'}{2} = 27°10'$

D. Transit setups on the curve

State that because of obstacles it is often impractical or impossible to run all of a given curve with the transit at the P.C. (Ref. A, p. 721; Ref. B, p. 277)

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

Explain the procedure for running a curve when all of the curve cannot be staked from the P.C.:

1. Compute the deflections as for use at the P.C.
2. Set up at any point on the curve. Backsight (with the telescope inverted) at the last transit station with the vernier reading the deflection for the point sighted (as computed under 1 above).
3. To locate other points, plunge the telescope. Use the deflection angles for the next point as previously computed for use at the P.C.

Note that when the point used as a backsight is the P.C., the backsight vernier reading is zero.

VI. Compound Curve

Define the *compound curve* as a curve formed by two simple curves that have one common tangent and a common point of tangency. Both curves lie on the same side of the common tangent. (Ref. B, p. 289)

A. Point of compound curvature

Add that the point of common tangency (where the two curves join) is called the P.C.C., or the *point of compound curvature*.

Tell the class that the compound curve is not the best way to change direction. It is used whenever the *topography* makes it impossible to use a simple curve. It is also used whenever a design must be revised.

Mention that the compound curve is sometimes used to correct a condition where two simple curves are connected by a short tangent. This is known as a *broken back* curve.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
VII. Reverse Curve	Define the *reverse curve* as a curve formed by two simple curves that have a common tangent and a common point of tangency. Both curves lie on *opposite* sides of the common tangent. (Ref. B, p. 290)
	Draw a sketch showing a typical reverse curve.
	Emphasize that the reverse curve is undesirable in design although some uses do exist. The reverse curve is used for the connecting two parallel tangents and in some highway crossovers.
	Point out that a very popular use of this type of curvature is made by the railroads in slow-moving spurs. However, a short tangent is usually placed between the curves.
VIII. Spiral Curve	Define the *spiral* curve as a cubic parabola used to provide a transition (horizontally) from the tangent to the circular portion of a curve.
	Tell the class that the use of the spiral curve is questionable on the modern highway. With the advent of the 11- and 12-ft. lane, the demand for the spiral has dwindled. (Ref. A, pp. 724-726; Ref. B, pp. 291-292)
	Note that in the ordinary curve the change of direction is made abruptly at the P.C. On a highway curve a vehicle is traveling on a tangent and at the P.C. it is traveling on a curve.
A. Uses of the spiral	Point out that this type of curve is used extensively in foreign countries where economy dictates the width of the travel lane. The *clothoid*, or *Euler's spiral*, is used instead of the cubic parabola. These curves are more difficult to use and lay out in the field, but they are more mathematically exact.

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

B. The spiral illustrated

Draw a sketch of Figure 4 showing the cubic parabola. Explain that the radius of this curve is infinity.

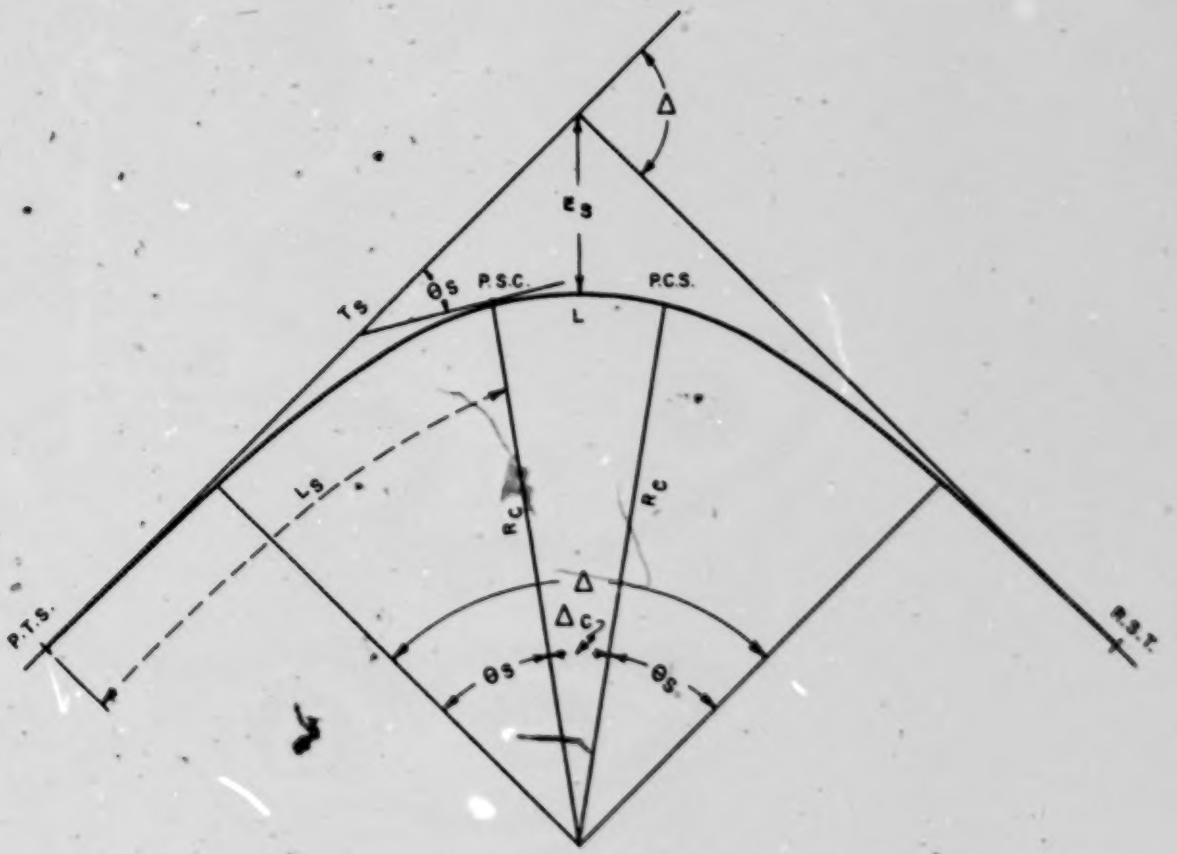


Figure 4
ELEMENTS OF THE SPIRAL CURVE

Show on an X-Y graph the most important elements of the curve:

1. The degree of curvature of the spiral varies. The limits are from zero at the beginning (the tangent to the spiral) to the maximum of the circular curve with which it is used.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	2. The offset y varies as the cube of the length of spiral.
	Draw a sketch of the spiral showing only the major elements. Point out that the spiral is rather complicated and that only the rudiments will be covered.
	Describe the parts of the curve using subscript s for the spiral and subscript c for the circular curve.
	Briefly note some of the relationships among the parts.
C. Reasons for the use of the spiral	Explain the effect on steering. The impact of centrifugal force cannot be absorbed instantly at the change of direction in the ordinary curve.
	Point out that the vehicle attempts to make its own path around the curve. At moderate speeds, most vehicles make the transition within the confines of the normal lane width. At high speeds and on sharp curves, the transition is made by hazardous banking or by going into the adjoining lane.
D. Advantages of the spiral	Advise the class that the spiral provides a natural, easy path to follow because the centrifugal force is gradually increased or decreased. The spiral:
	1. Minimizes encroachment on adjacent lanes
	2. Provides increased safety
	Add as much information as time permits on the geometrical analysis of the spiral. Mention that there are 23 items to be computed in the curve data.

QUESTIONS FOR REVIEW

1. What is the easiest way to achieve a change in direction from a tangent?

2. Identify the following notations used in horizontal curvature:

   (a) P.I. (b) P.C. (c) L (d) T

   (e) P.T. (f) R (g) E (h) M

3. Describe the *degree of curve*.

4. What is the radius of a 1° curve?

5. In stationing a curve why is it necessary to *backtrack* from the P.I. to the P.C. and then proceed around the curve to the P.T.?

6. What is the most convenient method of locating points on a curve?

7. Explain what is done when an obstacle prevents the location of any more points from the P.C.

8. Define a *compound* curve.

9. Define a *reverse* curve.

10. What is the main reason for using a *spiral* curve?

ASSIGNMENT

1. Solve problems 1-7 on page 726 of Ref. A.

2. Study pages 228-231 in Chapter 10 of Ref. A.

Lesson 13

VERTICAL CURVATURE

OBJECTIVES

1. To instruct the student about the geometry of the vertical curve
2. To instruct the student in the uses and computations of various types of vertical curve

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. The Vertical Curve	State that the *vertical curve* is an arc of a parabola. It is used because of 1. The gradual change in its direction 2. The ease in computing elevations along it Compare the vertical curve with the horizontal curve for effecting a gradual change between tangents. (Ref. B, pp. 280-281) Show by sketch how a vertical curve rounds off the intersection of two grade tangents. This curve acts as a transition from one grade tangent to another.
A. Classification	Tell the class that there are two classifications of vertical curve: the *sag* vertical and the *crest* vertical.
1. The sag vertical	Sketch and explain the *sag vertical* with these conditions: 1. A descending grade is followed by an ascending grade 2. A descending grade is followed by a flatter descending grade

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	3. An ascending grade is followed by a sharper ascending grade
	Define the first grade line (on the left in the sketch) as G_1 and the second (on the right) as G_2.
	Emphasize that a downgrade is always negative and an upgrade is always positive.
2. The crest vertical	Explain and sketch the *crest vertical* with these conditions:
	1. An ascending grade is followed by a descending grade
	2. An ascending grade is followed by a flatter ascending grade
	3. A descending grade is followed by a sharper descending grade
B. Controls	Mention that the design of vertical curves is controlled by considerations for *comfort* and *safety*.
II. The Geometry of the Curve	Indicate that the curvature adopted is the parabola whose equation is $y = ax^2 + bx + c$. (Ref. A, p. 229; Ref. B, pp. 281-284)
A. Sketch	Draw Figure 5 on the chalkboard and identify the various elements as they are discussed.
B. Nomenclature	Note that there is simplicity in using the parabola for curvature.
1. Point of vertical intersection	The *point of vertical intersection* of the grade tangents is the P.V.I.
2. Point of vertical curvature	The point where the vertical curve begins is called the *point of vertical curvature* or the P.V.C.
3. Point of vertical tangency	The *point of vertical tangency* is at the end of the curve and is denoted as the P.V.T.

CONTENT OUTLINE TEACHING POINTS AND TECHNIQUES

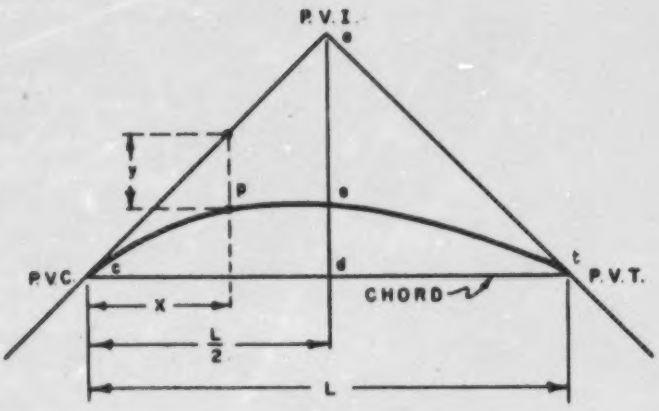


Figure 5
THE PARABOLA USED AS A VERTICAL CURVE

4. Symmetry

Point *d* is halfway from *c* to *t*. If points *c* and *t* are at different elevations, then point *d* is at the mean of these elevations.

Point *e* is halfway from point *a* to *d*.

5. Center correction

The distance from point *a* to *e* is the center correction, *H*, which is

$$H = \frac{G_1 - G_2}{8} \times \frac{L}{100}$$

1. $G_1 - G_2$ is the algebraic difference in percent between the two grades. It is always expressed as a positive number and, later, will be called *A*.

2. L is the length of the vertical curve in feet.

6. Length of curve

L is the horizontal distance from P.V.C. to the P.V.T., measured along the chord, and actually represents the parabolic curve.

7. Vertical tangent offset

The *y* distance is the vertical distance from a point on the grade tangent to a point on the curve.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
8. Horizontal distance	The x distance is the horizontal distance from one end of the vertical curve to any point on the curve.
C. Computations for elevations	Describe how the elevation of point P on the curve is found. The elevation of a point vertically above or below point P on the tangent must first be computed.
1. Point correction	State that a correction is made which is either subtracted or added to the elevation of the point on the tangent. Use the following formula for the correction to be applied to the tangent elevation for any point: $$y = \frac{x^2 H}{\left[\frac{L}{2}\right]^2}$$
III. Problems	Advise the class that the best way to become familiar with the variations of the vertical curve is to work out problems.
A. Ordinary crest vertical	Outline the following problem and solve it in two ways: Given a vertical curve of 400 ft., the P.V.I. at station 25 + 00 on the curve, at elevation 98.25, with a +4% grade and a -2.6% grade. Find the elevation of stations 24 + 25 and 25 + 00 on the curve.
1. Sketch	Draw Figure 6 to depict the problem.
	Compute the stations and elevations of the P.V.C. and the P.V.T.
	Find the center correction which will give the elevation on the curve at station 25 + 00. This correction is $$H = \frac{G_1 - G_2}{8} \times \frac{L}{100}$$ $$= \frac{4 - (-2.6)}{8} \times \frac{400}{100} = 3.30'$$

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

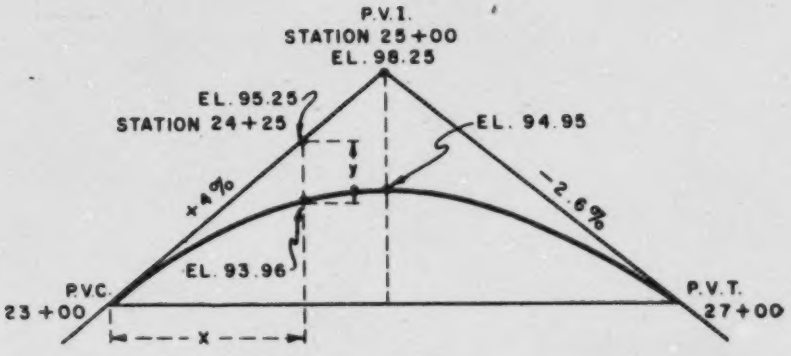


Figure 6
CREST VERTICAL

To get the elevation on the curve at station 25 + 00:

$$98.25 - 3.30 = 94.95$$

Now find the correction to be subtracted from the tangent elevation at station 24 + 25:

$$y = \frac{x^2 H}{\left[\frac{L}{2}\right]^2} = \frac{(125)^2\ (3.30)}{\left[\frac{400}{2}\right]^2}$$

$$= 1.29'$$

Then 95.25 - 1.29 = 93.96

which is the elevation on the curve at station 24 + 25.

2. Alternate method

Draw Figure 7 to show another method of analysis. (Ref. B, pp. 284-285)

Compute the elevations of the P.V.C. and the P.V.T., and then extend the first grade tangent, L/2 or 200 ft., on the same grade, which is 4%.

State that station 27 + 00 will be 13.20 ft. higher than the elevation at station 27 + 00, at the P.V.T.

CONTENT OUTLINE TEACHING POINTS AND TECHNIQUES

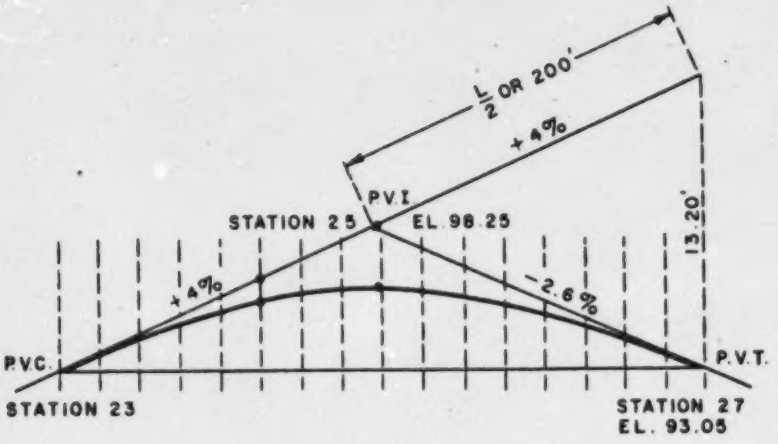


Figure 7
ALTERNATE ANALYSIS OF THE CREST VERTICAL

Call the center point the half-point of the vertical curve. From the laws of the parabola, $(\frac{1}{2})^2$ x 13.2 is equal to 3.30 (center correction).

Divide the total curve into 25-ft. segments (400/25, or 16 sections). Then station 24 + 25 is 5/16 of the total from station 23 + 00.

Point out that $(5/16)^2$ x 13.2 is 1.29 or that station 24 + 25 is 5/8 of the half curve. Then station 24 + 25 is $(5/8)^2$ x 3.30, which is 1.29.

B. Problem on the sag vertical

Recall to the students the appearance of the sag vertical and outline the following problem: Given a 600-ft. vertical curve on a +2% grade and a +5% grade. The P.V.I. is at station 7 + 00 at elevation 42.50. Find the elevation at station 7 + 75 on the curve.

1. Sketch

Draw Figure 8 to depict the problem.

Compute the station and elevation at the P.V.C. and P.V.T.

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

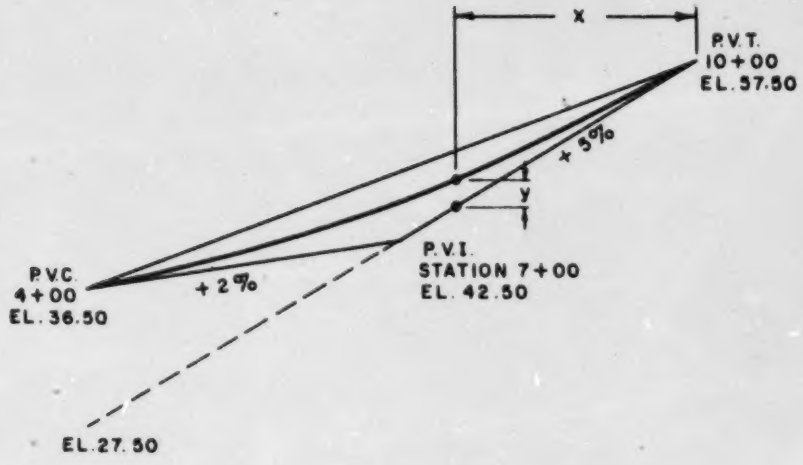


Figure 8
SAG VERTICAL

Compute the center correction:

$$H = \frac{G_1 - G_2}{8} \times \frac{L}{100}$$

$$= \frac{+2 - (+5)}{8} \times \frac{600}{100} = 2.25'$$

Compute the differential in elevation from the tangent to the curve at station 7 + 75:

$$y = \frac{x^2 H}{\left[\frac{L}{2}\right]^2} \quad \frac{(225)^2 (2.25)}{(300)^2} = 1.26'$$

Find the elevation at station 7 + 75; this is 46.25.

Note that the elevation on the curve at station 7 + 75 is 46.25 plus 1.26, or 47.51.

2. Alternate method

Use an alternate method, either by extending the forward tangent backward, or extending the back tangent forward.

Divide the length into 24 parts.

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

Observe that the forward tangent, extended backward 300 ft. ends at an elevation 9 ft. lower than the P.V.C. For the correction required at station 7 + 75, take $(9/24)^2$ (parts from one end) of 9 ft., or 1.26'.

Advise the class that $(9/12)^2$ of the center correction (using half of the curve) is also 1.26.

C. Problem set up in tables

Mention that there are times when it is expedient to use a tabular form for a problem. Here is an example: Given a 1,000 foot vertical curve with a -5% grade meeting a +7% grade at station 22 + 00, at elevation 432.00. Find the elevation at each station on the curve.

1. Sketch

Draw a simple sketch of the problem.

Compute the center correction:

$$H = \frac{G_1 - G_2}{8} \times \frac{L}{100} = \frac{AL}{800}$$

$$= \frac{(12)(1000)}{800} = 15.00$$

Compute the correction for station 18 + 00 to use as a check:

$$y = \frac{x^2 H}{\left[\frac{L}{2}\right]} = \frac{(100)(15)}{(500)^2} = 0.6'$$

Lay out a table of four columns: stations, elevations on tangents, differential corrections, and elevations on the curve.

Fill in the first column by inserting the stations and then computing the tangent elevations of those stations.

Make use of the parabolic law instead of the formula, and compute the corrections for each station, e.g., Station 18 + 00.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
IV. Special Problems	Emphasize that in many instances variations of the simple vertical curve are employed to solve special problems.
A. Low point	Explain that it is very important to find the low point of a sag vertical curve. This applies especially for drainage work or whenever a bridge is built on a sag vertical. (Ref. A, p. 231; Ref. B, pp. 286-287)
1. Sketch	Draw Figure 9 to show a low point problem.

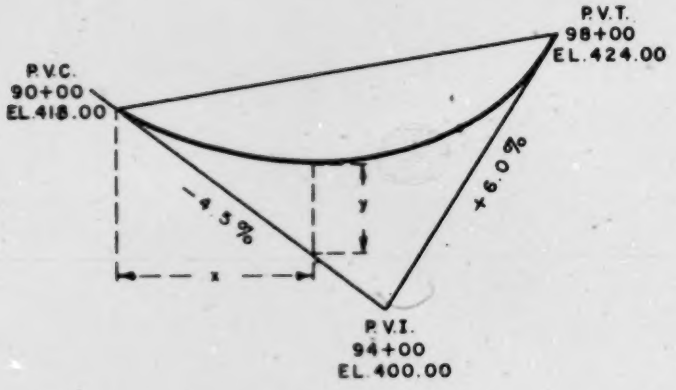


Figure 9
SAG VERTICAL
(Low Point)

2. Problems	Outline the following problem: Given an 800 ft. vertical curve with the P.V.I. at station 94 + 00 at elevation 400.00. Grades are at -4.5% and +6.0%. Find the station and the elevation of the low point of this vertical curve. Use the following formula:

$$x = \frac{\text{Grade of flatter gradient (L)}}{A}$$

Note that this gives the station of the low point. If the length of curve is given in stations, the answer will be in stations:

$$x = \frac{(4.5)(8)}{10.5} = 3.43 \text{ stations}$$

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	Point out that the low point is 3.43 stations, or 343 ft., beyond the P.V.C. (station 90 + 00), or at station 93 + 43.
	Find the elevation of the low point by using the following formula: $y = \frac{x^2 A}{2L}$; where x and L are stations $y = \frac{(3.43)^2(10.5)}{16} = 7.71'$
	Note that 7.71 ft. is the correction to be added to the elevation on the tangent at station 93.43. This is 402.56.
	Note also that the elevation of the low point is 402.56 plus 7.71 or 410.27.
B. High point	Show that the high point is computed in the same manner.
	Work out a simple problem for a high point.
C. Unsymmetrical curves	Explain that there are times in highway design when ordinary curves will not fit the field conditions.
	Use an approach to an intersection as an example where it would be more advantageous to use a vertical curve with unequal tangents.
	Call this curve an *unsymmetrical* vertical curve.
1. Problem	Outline the following problem: Given two grades intersecting at station 41 + 00, one grade at +6%, the other at -3%. Use a vertical curve of 600 ft. composed of two sections, L_1 of 400 ft. and L_2 of 200 ft. Find the elevation on the curve at station 40 + 00 and at station 42 + 00.
2. Sketch	Draw Figure 10 to show the problem.

CONTENT OUTLINE TEACHING POINTS AND TECHNIQUES

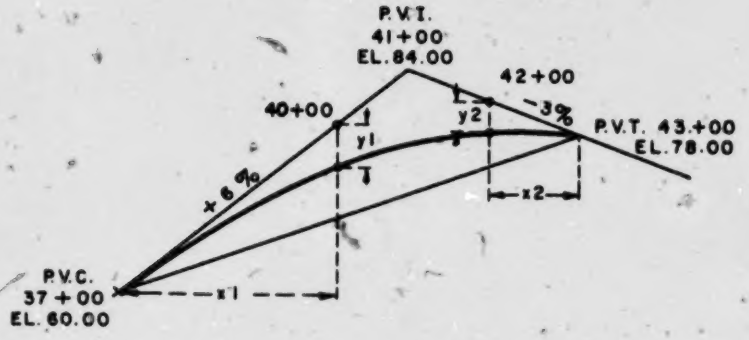


Figure 10
UNSYMMETRICAL VERTICAL

Find the center correction using stations and decimals of stations instead of feet:

$$H = \frac{L_1 L_2 A}{2 (L_1 + L_2)} = \frac{(4)(2)(9)}{2(4 + 2)} = 6.0'$$

Find the elevation at station 40 + 00 on the tangent. This is 78.00.

$$y_1 = \frac{x_1^2 H}{L_1^2} = \frac{(3)^2(6)}{4^2} = 3.37'$$

78.00 - 3.37 = 74.63, elevation at station 40 + 00, on the curve

Find the elevation at station 42 + 00 on the curve. The tangent elevation is 81.00:

$$y_2 = \frac{x_2^2 H}{L_2^2} = \frac{(1)^2(6)}{2^2} = 1.5'$$

81.00 - 1.5 = 79.50, elevation on the curve at station 42 + 00

QUESTIONS FOR REVIEW

1. What type of curvature is used to effect a change in vertical alignment?

2. Name three types of *sag* vertical curves.

3. Name three types of *crest* vertical curves.

4. Identify the following notations used in vertical curvatures:

   (a) P.V.I. (b) P.V.C. (c) P.V.T.

   (d) L (e) A

5. What distance is called the *center correction*?

6. How is it possible to compute a vertical curve problem without using formulas?

7. Where would an *unsymmetrical* vertical curve be used?

ASSIGNMENT

1. Give the following problem to the class to do at home: A P.V.I. is at station 25 + 00 at an elevation of 880.00. The tangents are at +5% and a -4%. There exists a *hold* control on the vertical curve for a railroad which is at station 26 + 00, elevation 873.00. Find the length of curve.

HINT: Draw Figure 11 to explain the problem.

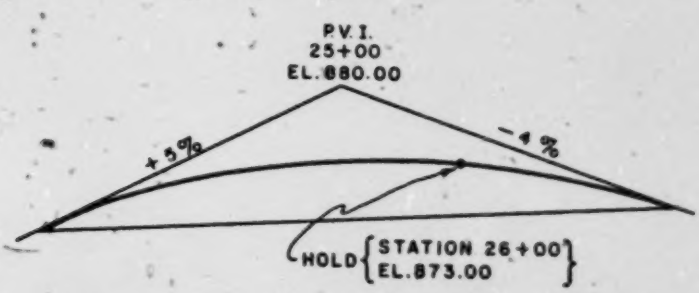


Figure 11
PROBLEM USING A *HOLD* CONTROL

   a. Note that the elevation at station 26 + 00 on the tangent is 876.00, which makes y equal 3 ft.

   b. Call the x distance, from the hold control at station 26 + 00 to the right end of the curve, equal to $\frac{L}{2} - 100$

   c. Use the formula $y = \frac{x^2 H}{\left[\frac{L}{2}\right]^2}$ Substitute the value of $\frac{L}{2} - 100$ for x and solve for L. This is 600 ft.

2. Solve problem 6 on page 232 of Ref. A.

3. Study pages 680-709 in Chapter 26 of Ref. A.

4. Study Chapter 28, pages 728-739 of Ref. A.

Lesson 14

THE PRELIMINARY, CONSTRUCTION, AND FINAL SURVEYS

OBJECTIVES

1. To teach the student the basic elements that make up the preliminary survey, the construction survey, and the final survey
2. To identify the major differences in the procedures
3. To show the sequential operation of the three surveys

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
I. The Pattern of the Designated Survey	Point out that in the design and construction of a highway the survey is actually the complete control. This control extends from the inception of an idea to the design plan, from the drafting board to the field, and from the field to the finished highway. (Ref. A, pp. 682-686)
A. Types of survey	Explain that there are essentially three basic types of survey: *preliminary*, *construction*, and *final*. Each one can be broken down into smaller divisions.
B. Similarities	Note that all these surveys have similar features.
1. Accuracy	Tell the class that every survey must be accurate within the allowances given.
2. Permanency	State that all surveys are a part of the permanent record of a project. This record must be treated for permanency in the field work and in the recording of the notes.
3. Relationship	Stress the importance of the relationship of one type of survey to another. Surveys must be easily identified with each other, because the *preliminary*

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	survey controls the *construction* survey, and the *construction* survey controls the *final* survey.
II. The Preliminary Survey	Explain that the *preliminary* survey includes all of the topographic information concerning alignment of a proposed highway. (Ref. A, pp. 689-694)
A. The reconnaissance survey	Point out that this survey precedes the preliminary survey. It is the informal act of selecting the *general location* of a highway. (Ref. A, p. 686)
1. Method	Mention that the survey is made by walking, riding, or flying over a given area. U.S. Coast and Geodetic Survey maps and aerial photographs are used as guides. The equipment used is limited to a 100-ft. tape, a hand level, and a compass.
2. Description	Describe this survey as a rapid examination made to indicate which alignment would afford the best route.
B. The base line survey	Note that the *base line* survey is commonly called the *preliminary survey*. We make this survey specifically to collect information by measurement and observations supported by notes. Mention that this could incorporate the reconnaissance survey by the survey party running more than one base line.
1. Equipment	Advise the class that complete surveying equipment is required for this work.
2. Extent of survey	Indicate that all the topographic information concerning the area is secured with cross-sections. This is required so that when the information is plotted, it will be an accurate representation of conditions in the field. The designer can then determine new alignment of grades, cutoffs,

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	intersections, foundations, drainage, bridge design, right-of-way, and other engineering features.
3. Area	Point out that in the advance programing of a project, certain data is secured and computed concerning existing and future traffic. This data prescribes the classification of the highway that is needed. As soon as a proposed highway is classified, standards are available as to the width of right-of-way required. State that the width of right-of-way dictates, in most cases, how far out at right angles from the base line the survey will go. This is never a shorter distance than the necessary right-of-way distance.
4. Techniques of the base line	Explain the use of the base line by using a sketch. Point out that this is merely a reference line to which everything else is related. Show that this line is used to provide an exact picture of what is on the ground. Emphasize that by using a base line as a reference line, a centerline can be established from one point to another point. The centerline may fall on the base line, close to it, or at a distance from it. On occasion the centerline may cross the base line.
C. Procedure of the preliminary survey	State that the very first step in the preliminary survey is the designation of the *path* or *line*. Secure all maps and plans of the area to use for reference.
1. Location on old alignment	Indicate that if the proposed highway is in the vicinity of an existing highway, all record plans and right-of-way maps of highways should be obtained.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
2. U.S. Geological Survey maps	Study the U.S. Geological Survey topographic maps of the area. Obtain a list of all the official bench marks and triangulation points in the vicinity. These are shown in the U.S. Geological Survey files.
3. Base-line alignment	Explain that if the program data requires that the proposed highway follow an old alignment, the base line should be run as close to the old centerline as possible. Use of the edge of the existing pavement as a base line would be ideal and would provide a parallel reference line. Suggest that it may be expedient to run the stationing as close as possible to the old centerline stationing. Remind the class that very often the base line will cross the new centerline. Show the class by means of sketches how the centerline stationing is equalized to the base-line stationing.
4. Orientation	Establish a *true north azimuth* for the base line at its beginning. This should be checked every mile or two, and it must also be checked at the end of the line.
5. Running the base line	Point out that the base line is run in even 100-ft. stations with all of the transit points tied. This means that all of the angle points and all of the *points on line* (P.O.L.) are tied together. Select points for ties which will remain undisturbed for years. (This is necessary because the highway may not be built for many years.) The points should be protected from traffic. Protection is also required against maintenance equipment, plows, mowing machines, and children.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	State that all transit points should be tied to a minimum of three points, preferably four, and give reasons.
	Paint the transit point stationing identification on the nearest pole, tree, or rock for ease in location.
	Indicate that the best procedure is to run the base line first, from beginning to end. Then the survey should return to the beginning and pick up the topography.
6. Location of topography	Locate all the important available topography, either manmade or natural. This should be done by *right angle offsets* from the base line or by angles and distances from a transit point (radiation method).
	List the topography generally located:
	1. Buildings and houses
	2. Culverts and bridges
	3. Curbs, sidewalks, and edges of pavements
	4. Sewers, catchbasins, and manholes
	5. Underground conduits, manholes
	6. Water pipes, water valves, hydrants
	7. Gas mains, gas valves, meter boxes
	8. Trees, shrubs, hedges, orchards
	9. Powerlines, towers, poles
	10. Woods, swamps, gardens, cultivated fields
	11. Property lines, stone walls, property monuments, retaining walls
	12. Rock outcrop, rock ledges

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	13. Intersecting roads, driveways 14. Names of property owners 15. Names of creeks and local names of natural items and roads Note that if a certain road classification demanded 120 ft. of right-of-way, topography must be picked up to a point beyond this limit. It is a good policy to extend at least 150 ft. on either side of the base line, unless the new centerline is forced to follow a known line.
7. Level run	Begin a level run at a recognized point of known elevation or at a U.S. Geological Survey bench mark. Establish bench marks in the vicinity of the base line, roughly 1,000 to 2,000 ft. apart. These marks should be closer together if the terrain is rough. Stress the value of placing one or two benches close to the vicinity of a proposed bridge. Point out that an object which cannot change elevation must be used for a bench mark. If nothing is available, show how to cut a tree near the root for the mark. Tell the class that if no trees, large stones, or foundations, etc. are available, large stakes should be driven into the ground. These are used as a last resort and cannot be used after a winter's exposure. Explain that the foresights should equal the backsights (both under 500 ft.). All readings should be taken to the nearest hundredth of a foot. State that the level run can be checked at a known elevation or at a U.S. Geological Survey bench mark.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
8. Cross sections	Continue the level work by taking cross sections of the base line from a point well in advance of the proposed highway. The point should also be well ahead of the terminal point (1,000 to 1,500 ft.). State that sections are taken every 100 ft. when the ground features are uniform. Sections are taken every 50 ft. if the ground becomes more erratic. Add that if the topography is rough, it may be necessary to secure cross sections at 25-ft. intervals or possibly at 10-ft. intervals. Advise the class that if any creek is encountered, it may be wise to take a sideline and to cross section the creek for 1,000 to 1,500 ft. Show how a *skewed* section is taken at any point on the stationing. This is used to give a better picture of a skewed culvert or some other odd feature in the terrain. Advise the class that the limits of a cross section should always exceed the limits of the topography. The contours of the area a distance away from the base line could affect the drainage design. Note that if cross sections are not required of intersecting streets, drives, and railroad facilities, a profile must be taken. Indicate the importance of securing the elevations of pipe inverts, manhole bottoms, elevations of highwater marks, and elevations of ordinary high water.
D. Notes	Exhibit some survey notebooks and point out that there are several methods of recording. All of these follow the same general pattern.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
1. Transit notes	Explain the method used to record the base line run on ordinary, coordinate looseleaf note paper. Describe the system used to record topographic information and show how sketches assist the notes.
2. Level notes	Explain the method used to record cross section notes. Demonstrate what happens when notes for back stations are obtained from an H.I. in the vicinity of a forward station. Indicate the importance of carrying forward the H.I. Recommend a No. 3 pencil for note taking. This is soft enough to be read easily, yet hard enough not to smudge.
3. Latest type of note paper	Exhibit the new type of note paper being used for both transit and level notes. This is the 8½ x 11 in. vellum type paper which fits into a 14-ring aluminum notebook. Point out the following features of the paper and the form: 1. Toughness of the material in the paper 2. Quality of reproduction 3. Space for sketches on the transit note sheets 4. Decimal spacing of lines for quick changes in scale when sketching 5. Uniformity from sheet to sheet (Every entry has a place.) Distribute sheets to the class for examination. Indicate that the level note sheets are designed to be used in the

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	electronic engineering program for earthwork computation in the Burroughs B-5500.
4. Other records	List the items which should be recorded with the notes: 1. Dated daily record of the party personnel 2. Dated daily record of the weather, including temperature, wind, etc. 3. List of symbols and abbreviations used in the notes 4. List of all reference materials used, such as utility company maps, village records, town records, etc.
III. The Location Survey	Explain that the *location survey* is often described as the *construction survey* or *stakeout*. Actually there is very little difference between the two. (Ref. A, pp. 697-700)
A. Design information	Remind the class that the preliminary survey information is used to design the highway. Show by sketch, a given base line and assume a designed centerline. This may or may not begin on the base line. Have the centerline either close to or a good distance away from the base line. Explain that in the design there is always a mathematical tie. This is between any point on the base line and any point on the centerline.
B. Location of the centerline	State that the first step in the resurvey is to relocate the base line. The base line is run without taking any topography. Add that the transit points should be retied beyond the limits of the construction if possible.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	line. Reiterate that this was the basis for computing the *earthwork*.
	Take a sample set of notes and draw a cross section from the data.
	Point out that data on the location of the original ground and the position of the base line are inked on the cross section drawing. The theoretical position of the proposed centerline is penciled in.
	State that the resurvey sections will be taken at right angles to the new centerline. This affords a better comparative picture of what will be changed by the construction.
	Remind the class that the period between the preliminary survey and the resurvey could be any time from one year to three years or more. Taking the resurvey sections in the above manner eliminates one of the possibilities of claims in earthwork quantities.
2. Slope stakes	Explain that the *slope stakes* are set at the point of intersection of the proposed fill slope or proposed cut slope with the original ground. These points are measured from the preliminary cross sections. Involved is the distance from the new centerline to the toe of slope or to the top of slope. This is the cut section on the left and right of the centerline.
	Note that these stakes are usually placed on the left and right of the full station centerline, but only on one side at the 50-ft. point.
	Explain that stakes can be placed before cross sectioning is done or during the cross sectioning process. The elevation of the ground next to the stake and the elevation of the stake itself are recorded.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
1. The new centerline	Point out that the next step is to lay out the centerline. So far, this centerline exists only on paper. There is a precise relationship between the base line and the centerline.
2. Curves	Indicate that the designed curves are staked out as a part of the centerline with the P.C. and the P.T. usually tied to the base line. The P.I. is always tied to the base line. Mention that these points should also be tied to some reference point in the field.
3. Physical evidence	Tell the class that the centerline is marked by a lath at the 50-ft. points (25-ft. points on curves). The stations are marked with blue keel on the lath. Repeat that whenever points such as a centerline station, a P.C., or a P.T. are referenced, the stakes should be outside the construction limits.
C. Resurvey levels	Stress the importance of *rerunning* levels and checking all of the bench marks for location and elevation. Point out that at this time the location of the centerline is known. All bench marks which will be destroyed by construction should be relocated to some safe point. This should be as close as possible to, but outside the limits of construction. Study all bridge plans so that new benches may be placed in the best possible location for use at the bridge site.
1. Cross sections	Draw a sketch showing the relative position of the new centerline with the base line. Show how the preliminary cross sections were taken at right angles to the base

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	Mention that the stake is usually offset from the actual point. This offset is marked on the stake together with the station mark.
D. The stakeout	Recap the preliminary steps: The centerline has been staked, the bench marks checked or relocated, and the new cross sections taken. Following these steps the major portion of the construction survey work consists of setting stakes for the guidance and control of construction operations. (Ref. A, pp. 729-731)
1. Right-of-way	Describe by sketch the operation of staking out the right-of-way. Show several copies of typical right-of-way appropriation maps. Explain briefly the principles of appropriating property. Advise that stakes are placed on the new right-of-way line at every break or angle point as indicated on the plans. State that all right-of-way is tied to the base line and not the centerline. Add that a stake (marked R.O.W.) is driven and a piece of red flag tied on a piece of lath (witness marker).
2. Clearing and grubbing	Explain *clearing* and *grubbing*. Prior to this operation a marked lath should be placed just outside the working limits but inside the right-of-way line.
3. Finishing stakes	Describe *finishing stakes* as earthwork stakes set for continuing survey work pertaining to grades. Point out that after the rough grading is finished, earthwork stakes are placed. These are set in the centerline or on the shoulder line, or offset a certain distance from the center-

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
	line. Finishing stakes are placed by the surveyor as requested by the contractor. Note that this operation also ties in the centerline. Mention that these stakes are marked with the amount of cut or fill necessary at the point affected.
4. Pavement stakes	Tell the class that *pavement stakes* are generally placed 2 ft. outside the edge of pavement. These are placed every 50 ft. on both sides for tangents, and every 25 ft. on both sides for vertical and horizontal curves.
E. Structure stakeout	Stress the importance of tying in the major lines of a bridge: e.g., the centerline of bearings, the centerline of a pier or an abutment, etc. Point out that these stakes should be from 100 to 300 ft. away from the structure. Conditions in the vicinity of a bridge site are not conducive to retaining anything on the ground; therefore, it is a good idea to use double stakes for insurance. (Ref. A, pp. 734-736) Describe the staking that would be requested for other portions of the bridge construction: e.g., footing alignments, pile driving patterns, alignment for piers and abutments, etc. Note that throughout the bridge construction, elevations are given for each phase of the work. State that all alignments and grades are given for the culverts in the project. Inform the class that in general there is considerable reestablishment of lines, points, and grades throughout the entire construction project.

CONTENT OUTLINE	TEACHING POINTS AND TECHNIQUES
IV. The Final Survey	State that the *final survey* occurs after construction and before the final estimates for payment are made.
	Impress on the class that the actual finished centerline must be tied for the preparations of *record plans* and for office review of the project.
	Note that the base line used for this survey is the finished centerline, and cross sections are taken from this line.
	Mention that the finished cross-sectioning is placed with colored ink on the preliminary cross sections.
	Stress to the class the importance of the final survey. Earthwork quantities are paid for by a comparative differential between the resurvey cross sections and the final cross sections.
	Explain that all structures, manholes, drop inlets, sewer lines, pipe underdrains, etc. are recorded. The elevations of culvert inverts are also recorded.
	Add that pavements are measured and recorded, with emphasis being placed on intersections.
	Explain that the finished project may not be exactly as designed. The final survey serves as a check to show *as-built* conditions.
	State that the original base line is also retied and brass plugs are placed whenever the transit points fall on new pavement.
V. Final Examination	Note: It is recommended that the examination at the end of this unit be given at this time. Allow a maximum of 1 hour for its completion. Sufficient time must be reserved for correction of the answer papers by the students.

CONTENT OUTLINE

TEACHING POINTS AND TECHNIQUES

Advise the students that the examination is not for grading purposes. The exam is intended to point out weak areas in the understanding of the material.

Suggest that additional mastery of highway surveying will be gained by the discussion that will follow the examination.

Point out the desirability of retaining notebooks and textbooks as sources of review for the future.

QUESTIONS FOR REVIEW

1. What are the *basic types* of surveying in highway work?
2. What is the main difference between the *reconnaissance* survey and the *base line* survey?
3. Explain briefly where a base line is run and how it is preserved for the future.
4. How is topography located from the base line?
5. For what distance beyond the terminal points of a highway should *cross sections* be taken?
6. Why is it necessary to deviate from the *right angle cross section* when a road, a creek, or a railroad is intersected by the base line?
7. What is the first step in the *resurvey*?
8. From what line of reference are the *resurvey cross sections* run?
9. Explain why it is necessary to place *slope stakes* for the new centerline?
10. What reference line is used for the *final survey*?
11. Why is the final survey especially important to the contractor building the highway?

PART I - TRUE OR FALSE STATEMENTS

INSTRUCTIONS: On the line provided, write the letter *T* if a statement is true and *F* if the statement is false. (Correct answers are shown in the answer spaces.)

T 1. In geodetic surveying the spheroidal surface of the earth is always taken into account regardless of the area being mapped.

T 2. A vertical line is by definition a plumb line.

F 3. An instrument man who suffers from astigmatism could possibly make a conditional error.

F 4. Both systematic errors and random errors follow laws of probability.

T 5. The technique of subtense is comparable to stadia surveying.

F 6. The rear tapeman checks for horizontal positioning whenever the taping operation advances downhill.

F 7. The most accurate method used to determine the difference in elevation between two points is barometric leveling.

T 8. The wye level has many more parts than the dumpy level.

T 9. The principle of the vernier is based on the fact that the lengths of the divisions on the vernier are slightly less than the lengths of the divisions on the scale.

T 10. If the H.I. of a level is 875.50 and a foresight reading on a B.M. is 2.50, the elevation of the B.M. is 873.00.

F 11. The balancing of backsights and foresights eliminates errors in the level.

T 12. The agonic line is also an isogonic line.

F 13. A transit is completely locked with the vertical crosshair set on a range pole. It is only necessary to free the lower motion and set the vertical crosshair on the second range pole in order to measure a horizontal angle.

T 14. The latitude of a point on the surface of the earth is the angular distance measured along the meridian from the equator to the zenith of the point.

F 15. A 1000-ft. vertical curve is placed on a grade of +5% and -4%, with the P.V.I. (elevation 200.00 ft.) at station 50 + 00. The elevation of station 45 + 00 of the curve is 185.00 ft.

__T__ 16. With the transit at the center of curvature any deflection is twice what it would be to the same point if the transit were at the P.C.

__T__ 17. When the delta angle of a curve is 90°, the tangent distance is equal to the radius.

__F__ 18. The mean solar time is based on the true solar day, or the interval of time between two successive lower transits of the sun's center over a meridian.

__T__ 19. The direction of the side of error in a closure is denoted by the angle whose tangent is equal to "the error in departures" divided by "the error in latitudes."

__F__ 20. Parallax may be eliminated by using a longer sunshade on the telescope.

PART II - FILL-IN STATEMENTS

INSTRUCTIONS: Complete the following statements. (The correct answers are shown in parentheses at the end of each statement.)

1. The limits of a cross-section should _____ the limits of the topography obtained. (exceed)

2. The _____ is equal to one-eighth of the algebraic difference in percent between two grades, times one-hundredth of the length of curve. (center correction)

3. The _____ curve utilizes the geometry of the cubic parabola. (spiral)

4. The formula 0.3CD will furnish the total deflection from the P.C. to the P.T. in _____. (minutes)

5. In a 1° curve, 1° of central angle will subtend an arc of ___ ft. (100)

6. In general the measured length of a line is _____ than the true length. (longer)

7. If B.M. No. 6 is at 966.24 ft. and a rod is read at 6.24 ft., the H.I. is _____ ft. (972.48)

8. The right angle prism is used primarily in _____ leveling. (cross section)

9. An ascending grade followed by a sharper ascending grade is a ___ vertical. (sag)

10. Magnetic dip is __ degrees at the magnetic pole. (90)

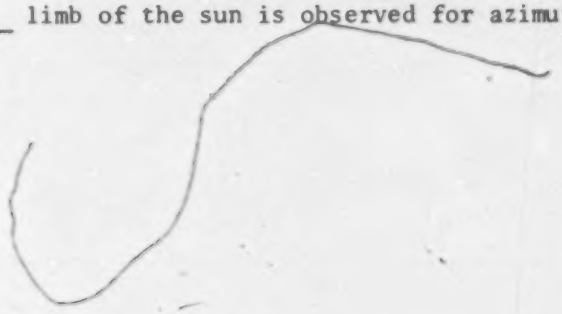
11. In a closed polygon the algebraic sum of the deflection angles is ___ degrees when the right deflection angles are considered to be opposite the left deflection angles. (360)

12. The expression _____ means to turn the transit telescope about its transverse axis. (plunging)

13. The line of _____ is the optical line of sight passing through the optical center of the telescope lens and the intersection of the crosshairs. (collimation)

14. The procedure of observing a horizontal angle and the distances to many objects from one position of the transit is called _____. (radiation)

15. The ____ limb of the sun is observed for azimuth. (east)



PART III - MATCHING

INSTRUCTIONS: Write on each line provided in Column A the number of the expression in Column B which is best suited. (Correct answers are shown.)

Column A		Columb B
3	New H.I.	1. Incorrect tape length
9	Bearing angle cosine	2. Least count
13	Balancing a traverse	3. Turning point
10	Long Island	4. Foresight
12	R tan $\frac{\Delta}{2}$	5. Swing offsets
2	Vernier	6. Triangulation
15	Parabola	7. Radiation
6	Inaccessible distance	8. Resection
17	Curvature and refraction	9. Latitude
19	R = 1910'	10. Lambert conformal projection
1	Systematic error	11. Celestial equator
8	Transit location unknown	12. Tangent distance
20	Sunshot	13. Compass rule
4	Minus sight	14. External distances
18	Index error	15. Vertical curve
		16. Spiral curve
		17. 0.021 M^2
		18. Vertical circle
		19. D = 3°
		20. True meridian

PART IV - MULTIPLE CHOICE

INSTRUCTIONS: Read all possible answers and then place an *X* in the space next to the choice which most accurately answers the question or completes the statement. (Correct answers are shown.)

1. In taping, which source of error would give the least amount of error to a measurement?

    _____(a) Variation in temperature
    _____(b) Sag in the tape
    _____(c) Errors in plumbing
    _X_(d) Imperfect alignment

2. The perimeter of a traverse was measured as 9900.00 ft. in January at a temperature of 0° F. The line was checked in July at a temperature of 90° F. What was the summer length of the line?

    _____(a) 9900.00'
    _____(b) 9957.92'
    _X_(c) 9894.25'
    _____(d) 9905.75'

3. What instrument is best used in stadia surveying?

    _____(a) Dumpy level
    _X_(b) Transit
    _____(c) Wye level
    _____(d) Self-leveling level

4. If the rod reading on B.M. No. 19A at elevation 414.06 is 6.52', what is the elevation of the top of the pedestal on a pier when the rod placed there is read at 2.08'?

    _X_(a) 418.50
    _____(b) 422.66
    _____(c) 405.46
    _____(d) 416.14

5. By the laws of probability the error in a line of levels can be expected to be proportional to the _____ of the number of setups.

    _____(a) Square
    _____(b) Cube
    _X_(c) Square root
    _____(d) Cube root

6. The instrument errors affecting the transit are:

    _X_(a) Systematic
    _____(b) Accidental
    _____(c) Random
    _____(d) Personal

7. The magnetic bearing of a line was found to be S20°30'W in an area where the magnetic declination is 12°30'W. What is the true bearing of the line?

_____(a) S32°30'W
__X__(b) S8°00'W
_____(c) S12°30'W
_____(d) S8°00'E

8. The true bearing of a line AB which lies on the agonic line is N17°45'W. What is the magnetic bearing of AB?

_____(a) N17°45'E
_____(b) Due north
__X__(c) N17°45'W
_____(d) Indeterminate

9. If the upper and lower clamps of a transit are locked and the horizontal circle reads 0°00'00", what would the horizontal circle read if the lower clamp was unlocked and the telescope turned one quadrant?

_____(a) 90°00'00"
_____(b) 45°00'00"
_____(c) 180°00'00"
__X__(d) 0°00'00"

10. Resectioning is actually the operation opposite from:

_____(a) Radiation
__X__(b) Intersection
_____(c) Triangulation
_____(d) Balancing-in

11. If the algebraic sum of the latitudes is +0.24 and the algebraic sum of the departures is -0.32, what is the linear error of closure?

_____(a) 0.56
__X__(b) 0.40
_____(c) 0.08
_____(d) 0.16

12. In problem 11 what is the direction of the closure?

_____(a) Northeast
__X__(b) Northwest
_____(c) Southwest
_____(d) Southeast

13. The stadia interval factor for most transits is:

_____(a) 1.00
__X__(b) 100
_____(c) Variable
_____(d) 1000

14. At a certain instant the time is 9:45 a.m., Pacific Standard Time. The location is at longitude 128°50'50" where standard time is based on the 120th meridian. What is the local civil time?

_____(a) 9:13:00 a.m.
_____(b) 10:20:23.4 a.m.
_____(c) 10:13:00 a.m.
__X__(d) 9:09:36.6 a.m.

15. The azimuth of the sun (Z) is always measured:

__X__(a) From the north
_____(b) From the south
_____(c) Clockwise
_____(d) Counterclockwise

16. The tangent distance is equal to the radius of a simple curve when Δ is:

_____(a) 30°
_____(b) 45°
_____(c) 60°
__X__(d) 90°

17. The P.C. is at station 126 + 00, the P.T. is at station 136 + 00, and Δ is 36°. What is the deflection angle to the center of the curve?

_____(a) 18°
_____(b) 15°
_____(c) 12°
__X__(d) 9°

18. On a 600' vertical sag curve, the grades are -2% and +4% with the P.V.I. at station 50 + 00. What is the station of the low point?

_____(a) 47 + 00
_____(b) 48 + 00
__X__(c) 49 + 00
_____(d) 51 + 00

19. What information is marked on a slope stake?

_____(a) Amount of cut
_____(b) Amount of fill
__X__(c) Station
_____(d) Offset

20. If the horizontal circle of a transit is divided into 10-minute units and there are 60 spaces in the vernier, the least count is:

__X__(a) 10 seconds
_____(b) 12 seconds
_____(c) 15 seconds
_____(d) 20 seconds